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INTRODUCTION

The Institute for Computer Applications in Science and Engineering (ICASE) is operated at the Langley Research Center (LaRC) of NASA by the Universities Space Research Association (USRA) under a contract with the Center. USRA is a nonprofit consortium of major U. S. colleges and universities.

The Institute conducts unclassified basic research in applied mathematics, numerical analysis, and computer science in order to extend and improve problem-solving capabilities in science and engineering, particularly in aeronautics and space.

ICASE has a small permanent staff. Research is conducted primarily by visiting scientists from universities and from industry, who have resident appointments for limited periods of time, and by consultants. Members of NASA's research staff also may be residents at ICASE for limited periods.

The major categories of the current ICASE research program are:

- Numerical methods, with particular emphasis on the development and analysis of basic numerical algorithms;

- Control and parameter identification problems, with emphasis on effective numerical methods;

- Computational problems in engineering and the physical sciences, particularly fluid dynamics, acoustics, and structural analysis;

- Computer systems and software, especially vector and parallel computers.

ICASE reports are considered to be primarily preprints of manuscripts that have been submitted to appropriate research journals or that are to appear in conference proceedings. A list of these reports for the period April 1, 1989 through September 30, 1989 is given in the Reports and Abstracts section which follows a brief description of the research in progress.

Presently, ICASE is operated at NASA Langley Research Center, Hampton, VA, under the National Aeronautics and Space Administration, NASA Contract No. NAS1-18605. In the past, support has been provided by NASA Contract Nos. NAS1-18107, NAS1-17070, NAS1-17130, NAS1-15810, NAS1-16394, NAS1-14101, and NAS1-14472.

RESEARCH IN PROGRESS

Saul Abarbanel

The work concerning moderate Reynolds Number flows (Re < 100) was concluded. (This research was done with D. Gottlieb, W. S. Don, D. Rudy (Fluid Mechanics Division, LaRC), and J. Townsend (Fluid Mechanics Division, LaRC).) It was shown, both numerically and analytically, that even stable and consistent boundary conditions could induce spurious secondary phenomenon. Formulation of the boundary conditions in terms of the characteristic variables eliminated the non-physical frequencies. An analysis based on a simplified model provides an explanation for this behavior. Extension to the three-dimensional case will be explored.

The work on non-reflecting boundary conditions for wake flows progressed to a point where a graduate student modified a code for flow past an airfoil in order to test the procedure. Very preliminary results indicate an improved wake definition.

The work on the stability of Poiseuille flow of a slightly compressible ideal gas continues.

H. T. Banks and Fumio Kojima

We are continuing our investigations (in collaboration with W. Winfree of the Instrument Research Division, LaRC) on inverse problems arising in thermal testing of materials in space structures. Our focus for this problem is on the identification of the geometrical shape of boundaries for a thermal diffusion system. Using techniques and ideas related to the 'method of mappings', we have been able to develop a spline-based parameter estimation technique. The ideas developed are now being tested with the experimental data from IRD laboratories at NASA Langley. For various kinds of samples with corrosion (all of steel), experiments were carried out in IRD laboratories and for each of these experiments we used our estimation packages with the resulting data. In all cases, the algorithm performed extremely well and we believe this provides rather conclusive evidence that (i) structural flaws of this nature can be successfully detected using thermal methods, and (ii) the mathematical and computational ideas can be effectively used in determining the existence, location, and nature of such material flaws. We are currently pursuing both experimental and computational investigations to further refine our methods as well as to test other types of materials (aluminum, etc.) and flaws (e.g., delaminations) with regard to ease and accuracy in detection and characterization of flaws with thermal based methods.

Christine Bernardi

During my stay at ICASE, I worked on two recent aspects of to spectral methods: domain decomposition and approximation of compressible flows.

Coupling spectral methods with domain decomposition is performed in two different ways depending on whether these methods are based on either variational or collocation formulations. As far as variational techniques are concerned, the work focused on the recent "monitor" element method of Y. Maday, M. Macaraeg and C. Streett (Fluid Mechanics Division, LaRC) have very interesting numerical results for using collocation methods on several subdomains. Their technique relies on a "flux-balance" matching condition. I intend to establish theoretical justification of this approach for simple elliptic linear problems.

My work also concerns simple modes of viscous compressible flows, where the density is a given function of time and space or where the pressure is a given function of the density. The spectral approximations I propose coincide with the numerical experiments that are now performed, and I intend to give positive answers to the following questions: Is a compatibility condition necessary between the discrete spaces of velocity and/or density and pressure? Is it numerically reasonable to work with the primitive unknowns of velocity and density?

Harry Berryman, Charles Koelbel, Piyush Mehrotra, and Joel Saltz

We compare the effectiveness of different optimizations designed to permit a distributed machine to efficiently compute parallel loops over globally defined data structures. These optimizations are specifically targeted towards loops in which some array references are made through a level of indirection. Unstructured mesh codes and sparse matrix solvers are examples of programs with kernels of this sort.

We transform parallel do loops specified over globally defined data structures into code that executes on each processor. The code actually executed by each processor in a distributed memory machine references data structures that are stored in the processor's own memory. In order to carry out computations with reasonable efficiency, information stored off processor must be prefetched and stored in local memory. In programs of interest to us, until a program executes, we cannot accurately predict what data must be prefetched. To deal with this ambiguity, we transform a parallel loop at compile time to inspector and an executor loops. During program execution, the inspector loop analyzes the data references made in a loop, calculates what off processor information needs to be fetched, and where that information will be stored on processor. The executor loop uses information from the inspector loop to carry out the actual computation.

The data structures used to store off processor information in local memory are expected to play a significant role in determining the efficiency with which a computation can be

carried out. Some preliminary data on two different ways of designing inspector executor loops has been presented in ICASE Report No. 89-7 and a paper submitted to the Conference on Principles and Practice of Parallel Programming. We are now carrying out a more extensive study of inspector/executor methods for distributed machines. We are using both simple sweeps over meshes along with more realistic codes involving unstructured mesh calculations.

Harry Berryman, Piyush Mehrotra, Joel Saltz, and Jeffrey Scroggs

We have designed a set of primitives that allow us to map a globally defined multidimensional array onto a distributed memory machine in a manner that may be specified by a user. The primitives include procedures that allow one to fetch and store array references to the distributed memory of the machine. Other primitives are used to support relatively efficient caching of off processor data needed in computations performed by a given processor.

These primitives are being used in the coding of an adaptive partial differential equation solver and a program that carries out sweeps over an unstructured mesh. The emphasis of this project is to force us to develop a robust set of primitives that can be used to effectively port realistic programs to distributed machines. This set of primitives is being used both as a short term solution to porting programs to distributed memory machines and as a tool to allow us to systematically construct a distributed Fortran compiler (Kali Fortran).

Harry Berryman, David Nicol, Joel Saltz, and Jeffrey Scroggs

Adaptive methods to solve the PDEs that arise in the simulation of physical phenomena require the efficient utilization of parallel computers. Distributed and hierarchical memory architectures will provide the most cost effective computational power. This project examines the issues related to using adaptive-mesh algorithms in this environment.

We are using the Scroggs algorithm as a model problem to examine strategies for mapping and remapping changing workload to processors. One issue we address involves deciding when the potential advantage of repartitioning outweighs the overheads incurred. Another issue involves choosing what type of mapping should be used when we repartition.

This work may be regarded as a continuation of work described in

D. Nicol, J. Saltz, and James Townsend: *Delay point schedules for irregular parallel computations*. To appear in International Journal of Parallel Processing.

D. Nicol and J. Saltz: *Dynamic remapping of parallel computations with varying resource demands*, IEEE Trans. Comptr. 9, 37, pp. 1073-1087.

J. Saltz and D. Nicol: *Statistical methodologies for the control of dynamic remapping in parallel processing and medium scale multiprocessors.* Arthur Wouk (ed.), SIAM publications, 1989, pp. 35-57.

J. S. Scroggs: *A parallel algorithm for nonlinear convection-diffusion equations.* To appear in Proceedings for SIAM 1989 Conference on Domain Decomposition.

Richard J. Bodonyi

During a three week summer visit at ICASE, research, undertaken jointly with P. W. Duck, has been carried out on the problem of boundary-layer receptivity due to uniform suction through a slotted wall beneath an incompressible laminar boundary-layer flow.

A computer code has been developed for solving the nonlinear interactive triple-deck equations for the steady motion. Additionally, an existing code for the linearized disturbance flowfield developed by Bodonyi, Welch, Duck, and Tadjfar [Journal of Fluid Mechanics, 1989, to appear] has been modified to handle the disturbance flowfield for the suction slot problem.

The problem contains three parameters: 1) the wall suction parameter; 2) the slot length parameter; and 3) the scaled Strouhal number. To date, solutions have been found for a fixed value of the slot length parameter and selected values of the wall suction parameter and Strouhal number. A write-up of this research effort has begun and a paper will be submitted to the Physics of Fluids describing our results.

John Burns

We are continuing our effort to develop computational algorithms for identification and control of fluid/structure interaction problems. The basic approach is to formulate the problems as distributed parameter systems and to use standard approximation schemes to construct finite dimensional models for control design and optimization.

We are looking at several problems. In collaboration with Y. R. Ou, we are applying simple boundary element techniques to the problem of active control of flow separation over an airfoil with "flap." The basic numerical scheme has been developed and tested on an open loop simulation. This code is being extended to handle the dynamic case and will be used to "test" some of the basic control ideas.

There are several difficulties with controlling a fluid/structure interaction problem. The basic problem is always nonlinear due to the hybrid nature of the boundary conditions (even if the dynamics are assumed to be linear). The problem of constructing an appropriate

"linearized" model for control design is not straight forward. We are investigating simple models to gain some insight to the more complex physical problems. We have shown that for Burgers' equation, the LQR control design (based on the linearized model) enhanced stability and smoothed the closed loop solutions. We are investigating the effects of the state estimator on this smoothing process.

Richard Carter

The unification of structural optimization with the design of control algorithms is being considered in collaboration with E. Armstrong (Guidance and Control Division, LaRC). A nonarticulated antenna-buss structure is being examined as a trial case in order to develop methodology and to identify typical features of optimization problems of this type. A variety of merit and/or constraint functions can be used to formulate the problem: the choice of problem definition must currently depend not only on engineering goals, but also on the viability of numerically solving the problem using existing methods and computer hardware. The merit functions currently under consideration are typically both nonlinear and nonconvex, and some have piecewise discontinuous partial derivatives. At least one merit function under consideration has jump discontinuities near the solution due to eigenvalue switching in the reduced-order computational model of the structure.

Currently, work is being done to further identify potential difficulties with various approaches and to identify viable solution techniques. Nondifferentiable optimization methods which exploit the structure of the problem formulation are under consideration, as well as methods for unstructured nondifferentiable problems. The jump discontinuities associated with reduced order modeling are a greater difficulty. The most promising approach seems to be to treat the merit function as the sum of a smooth (ideal) model and a discontinuous perturbation. By including enough modes to ensure that the perturbation is "sufficiently small" with respect to observed changes in the overall model, this problem may prove amenable to a previously developed trust region approach which allows for noisy function evaluations.

Other techniques under consideration include adaptive nonlinear rescaling, direct search techniques, and techniques for exploiting parallel computation.

Stephen F. Cowley

A paper entitled "On the instability of hypersonic flow past wedges" was completed with P. Hall; some numerical solutions to Rayleigh's equation were obtained to confirm our earlier asymptotic solutions. This paper is to appear in the Journal fo Fluid Mechanics. We have now extended this work to include the effects of a more realistic viscosity law and to investigate the effects of "shock-wave heating" on the vorticity mode for hypersonic flow past thin bodies. A paper on this work is in preparation.

I have also obtained some numerical solutions for periodic boundary layer problems. This work is relevant to the sub boundary-layers which develop under very large Tollmien-Schlichting waves.

Finally, preliminary investigations are underway on the singularity formation in vortex sheets and how to remove the singularity by the inclusion of small amounts of surface tension, viscosity, sheet thickness, and/or thickness.

Thomas W. Crockett

The Intel iPSC/2 hypercube computer was installed, checked out, and brought online.

Work is in progress to evaluate the performance of the iPSC/2's Concurrent File System. Initial measurements show that the I/O bandwidth from the CFS to a single processor is 20-30 times greater than from the host's disk.

The X Window and the Andrew system were brought up on the new SPARC stations.

Naomi Decker

Several methods of adapting multigrid algorithms to massively parallel machines were analyzed. The PSMG method of McBryan/Frederickson and similar algorithms were shown to suffer the same affliction as the standard multigrid algorithms; there is not enough useful work to be done on coarse grids. This research has shown, for example, that in the PSMG algorithm, the work done on coarse grids by the otherwise idle processors is redundant and cannot substantially affect the convergence rate.

The main area of research continues to be directed towards understanding multigrid as a means of accelerating the convergence of explicit time stepping schemes for the steady Euler equations. A new analysis of the linearized scalar equations is being developed. Directly incorporating the boundary conditions for convective problems into the analysis has led to a more reliable method of predicting and improving the convergence properties of these algorithms. Work with Eli Turkel is directed towards understanding various anomalies in the performance of experimental codes for fluid flow over an airfoil. Isolating the various

possible causes of performance degradation is the main focus of this project.

Naomi Decker and John Van Rosendale

In recent work, we have designed a multigrid method based on zebra relaxation, and a new family of restriction/prolongation operators. Using zebra relaxation in combination with an operator-induced prolongation leads to fast convergence, since the coarse grid can correct all error components. The resulting algorithms are not only fast, but are also "robust," in the sense that the convergence rate is insensitive to the mesh aspect ratio. This is true even though line relaxation is performed in only one direction.

Multigrid becomes a direct method if one uses the right operator-induced prolongation, together with the "induced" coarse grid operators. Unfortunately, this approach leads to stencils which double in size on each coarser grid. Our algorithm, known as ZOOM (zebra optimized operator multigrid), relies on implicit three point restriction operators which approximately factor these large stencils. The result is an algorithm typically achieving V-cycle convergence rate of 0.03 on Poisson's equation, using one and a half zebra sweeps per multigrid level and five point stencils.

This new algorithm has been successfully applied to NASA elliptic grid generation problems, where its insensitivity to mesh aspect ratio is attractive. We are currently designing a variant of this algorithm to be used as a conjugate gradient preconditioner for the indefinite Helmholtz equation. There is also interest in using a variant of this algorithm to solve the systems arising in implicit spectral methods for compressible Navier-Stokes equations. At the moment, implicit spectral methods are rarely used due to the high cost of inverting the linear systems involved.

Michel Deville

Work focused on applications of spectral methods. The first topic is related to the fast Helmholtz solver in the Chebyshev-Tan approximation. The first space direction is diagonalized while the second space direction leads to tridiagonal systems. This algorithm may be parallelized and numerical tests have been performed on an Alliant computer.

The second research topic was concerned with three-dimensional transient Navier-Stokes equations. The Chebyshev collocation problem is preconditioned by finite elements. An obvious generalization from two-dimensional situations uses triquadratic interpolants for the velocities and the linear pressures. However, this element is computationally intensive. Therefore, other three-dimensional elements were considered such as the mini-element due to Arnold, Buzzie, and Fortin. The research is still in progress.

Wai Sun Don and John T. Crawford

We have been continuing the study of two-dimensional wake flow past a circular cylinder, begun by D. Rudy and J. Townsend (Fluid Mechanics Division, LaRC) and D. Gottlieb. The compressible, viscous Navier-Stokes equations are discretized by the Chebyshev-Fourier collocation method. Our goal is to examine the phenomenon of transition to turbulence in open flow systems. In order to increase the Reynolds number, multi-domain techniques will be employed to resolve the small-scale structures within the boundary layer. Currently, we are testing the spectral code at Reynolds number 250, which lies within the range of the onset of transitional effects.

Peter Duck

An investigation has been carried out into the (non-axisymmetric) temporal stability of the boundary layer which forms on the surface of a cone in a supersonic flow. A necessary condition for the existence of neutral "subsonic" modes has been derived (the "triply generalized" inflection condition) and computations have been carried out, using the appropriate (Rayleigh-type) instability equations. These reveal a blunt mode of instability peculiar to flows involving lateral curvature is possible, and details of this mode have also been described asymptotically.

Joint with R. Bodonyi, the problem of how small amplitude, unsteady, freestream disturbances in an incompressible flow interact with a surface section slot has been studied. This falls into the general category of receptivity problems, and leads to a prediction of the amplitude of the resulting Tollmien-Schlichting waves. This study has also illustrated the action of "active" control (by means of introducing unsteady wall suction), which enables an unsteady Tollmien-Schlichting waveform to be completely eliminated.

Thomas Eidson

The understanding of turbulent fluid flows is hampered because the non-linear governing equations (and physics) have very complicated solutions. One approach is to calculate as much detail as possible using the full equations, and another approach is to use a model to calculate the smallest and most numerous details and to directly calculate the large scale features of the flow. The current work is directed at using the first (more expensive) approach to better understand the second (less accurate) approach.

In collaboration with C. Speziale and T. A. Zang (Fluid Mechanics Division, LaRC) a three-dimensional, direct numerical simulation (first approach) of an incompressible, homogeneous shear turbulence will be computed along with a large eddy simulation (second

approach) of the same flow. The results will be compared to quantify the effect of the sub-grid mod· in the large eddy simulation.

The codes used in the above study are being rewritten to execute via parallel processing (initially on CRAY computers). Various strategies are being explored and compared.

In collaboration with M. Y. Hussaini and T. A. Zang (Fluid Mechanics Division, LaRC) a direct simulation of the turbulent Rayleigh-Benard problem was computed in 1985. Further analysis of this data is continuing. Currently, a coarser grid than originally used is imposed on the data calculated with a fine grid.

The terms of the kinetic energy equation for length scales smaller than the coarse grid are being calculated using the fine grid data. These calculated terms will be used to evaluate and suggest subgrid scale models which are usually derived from the subgrid scale energy equation.

Ami Harten

Together with D. Gottlieb, I have developed Godunov-type spectral methods: given cell averages of the solution at time-level n, we reconstruct approximations to spectral accuracy by evaluating the point values of the primitive function at the collocation points and differentiating its spectral interpolant. To compute the new cell averages at time-level $n + 1$ we calculate numerical fluxes which are approximations to the flux at the cell boundary in the solution to the IBVP with initial data of the reconstructed function.

The main difference between the Godunov approach and the previous pointwise approach is that the boundary conditions do not play any role in the reconstruction stage – this is considered to be an approximation problem within the Godunov approach; the boundary conditions there enter on the PDE level. Numerical experiments with a Godunov-like Chebyshev method indicate that the scheme is linearly stable.

Together with Y. Hussaini, I have continued the work on the collection of the ICASE sponsored research on TVD and ENO schemes.

Thorwald Herbert

A problem-independent spectral code to study linear, nonlinear, and secondary instability is under development. The code is augmented with an interactive and graphical user interface.

Nonlinear stability theory for nonparallel flows and numerical methods for solving nonlinear systems of the parabolized stability equations are under development. Studies on spectral computations of three-dimensional flows that depend on two variables, including

their bifurcations, linear and nonlinear stability are underway.

Together with G. Erlebacher (Fluid Mechanics Division, LaRC), study of the stability of compressible plane Couette flow with emphasis on the effect of approximations to the mean flow was undertaken focusing on analytical and numerical studies on the spectrum of eigenmodes. Comparison with the results of Glatzel (1989), Mack (1989), and Tam (1989) are being made.

Kazufumi Ito

Motivated by the equation appearing in the modeling of certain aeroelastic systems, we (with J. Burns) have studied a class of integro-differential equations with singular kernel. We developed a semigroup formulation using the weighted L_2-space as a state space. Such a state-space formulation enables us to develop a systematic approximation technique for constructing the optimal stabilizing feedback gain operator.

In joint work with H. T. Banks, a manuscript on "A Variational Approach to a Class of Boundary Control Problems" is nearly completed. In this paper the linear quadratic optimal control problem for parabolic systems is studied and the boundary control problems are formulated within the framework of Gelfand-triple. Convergence of the Galerkin solution to Riccati equations is established using functional analytic methods (especially the theory of analytic semigroup). Motivated by this study we (with H. T. Tran, North Carolina State University) have studied the linear quadratic regulator problem for a general class of systems involving unbounded input and output operators, especially including the delay differential control systems. An approximation theory is developed for the solution of the operator Riccati equation for the so-called Prichard-Salamon class.

Thomas L. Jackson and Chester E. Grosch

Our work focuses on the hydrodynamic stability of compressible high speed reacting free shear flows, directly applicable to the study of supersonic diffusion flames in the context of scramjet engines. Problems in this area are extremely complex, yet must be thoroughly understood. In tackling problems in this area, we have employed a combination of asymptotics and numerics to reduce the complex problems to model problems, thus isolating key physical effects for analysis. Most notably is the systematic study that we undertook in the classification of neutral and unstable modes of both a nonreacting compressible mixing layer and one in which a flame sheet is embedded. We are currently extending this work to include both near and far wakes, as well as more realistic kinetics using quasi-global models for the chemistry.

Charles Koelbel

The focus of this research is to compile programs written for a shared memory model to run on distributed memory computers. Briefly, this is accomplished by determining, either at compile time or run time, the list of references in the program which are not stored in local memory. Appropriate statements are then generated to communicate these values to the correct processors. We are currently developing a compiler which will compute the non-local reference lists statically (if that is possible) or generate the run-time code to compute the lists (if the analysis is not possible). The work is being done with P. Mehrotra.

Fumio Kojima

Work is continuing on the development of parameter estimation techniques based on the boundary integral equation approach. Boundary shape identifications based on boundary measurements have been studied for mixed boundary value problems. Those are formulated as the parameter estimation problem for an integral equation of the first and second kind. We developed a parameter estimation technique using spline based boundary approximations. Numerical calculations are being done successfully using an optimization routine based on a trust region algorithm created by R. Carter. Our current research interest is to study the stability and sensitivity of the algorithm with respect to data perturbations.

Richard J. Littlefield

Message passing parallel computers, such as the NCUBE and Intel hypercubes, have the potential to be fast and cost-effective for solving many scientific problems. Unfortunately, current programming tools often cause this potential to be lost. They make it too difficult and time consuming to write programs that are both correct and efficient.

We are exploring ways to make it easier to program these machines. Our work centers on a programming model involving synchronous operations on distributed data structures. The goal is to raise programming above the level of explicit message passing, by allowing executable code and data partitions to be specified independently. To the programmer, the machine appears to have shared memory. All message generation is handled automatically by the compiler and runtime system. The synchronous control model guarantees deterministic results and allows several optimizations for efficient communications.

Research is involved at several levels: programming model, language design, compilation and runtime techniques, and performance estimation and measurement. This work is expected to comprise a doctoral dissertation at the University of Washington (Seattle). Our brief stay at ICASE has provided a greater understanding of fluid dynamics applications and

has yielded a number of model problems to guide further computer science research.

Robert W. MacCormack

Recently, the stagnation region in supersonic flows past blunt axisymmetric bodies has received attention in computational simulations because of inaccurate predictions of stagnation point heat transfer. The causes cited for this loss in computational accuracy have ranged from errors calculated at the flow shock near the axis of symmetry, the carbuncle problem (Perry), to the rapid increase of some terms, proportional to r^3, (Blottner) in the conservation law formulation of the governing equations. The remedy for the latter cause, given by Widhof in the late 60's, is to recast the equation in conservation from at the axis, thereby reducing the order of the highest power terms to r^2, which are then well suited for second order accurate numerical methods. However, I have observed that errors created at the bow shock near the axis of symmetry were the predominant cause of poor stagnation point heat transfer predictions and that, once created, higher order accurate differencing (to third order) did not help sufficiently. Alignment of the mesh with the bow shock for either a shock fitting or shock capturing approach did improve stagnation point heat transfer predictions significantly.

Yvon Maday

The current research is focused on the following points:

- Development of the "mortar element method" (ICASE Reports No. 87-70, 88-59). This method allows one to couple the use of finite element and general spectral element discretization in different subdomains in a way adapted to the feature (regularity) of the solution. The purpose is to define, in the context of domain decomposition techniques, a method that is optimal in both a theoretical and a numerical point of view. By optimal in a theoretical point of view we mean a method able to provide a numerical solution such that

$$||\text{global error}|| \leq C \sum_{\text{subdomains}} ||\text{local independant best fits}||$$

as if the subdomains were not corrected. By optimal in the numerical point of view we mean a method that allows for using the best solvers adapted to each local method so as to build an efficient global solver. This work is in collaboration with C. Bernardi and A. T. Patera (M.I.T.).

- Extension of the spectral vanishing viscosity (see ICASE Report No. 88-4) with Kaber, E. Tadmor, and C. W. Shu. The first extension is related to the adoption of the method to nonperiodic situations. Numerical simulations have demonstrated the effectiveness of the method. The second one is related to the analysis of the full discretization of this method and its relation with the application of a proper filter at each time step.

- Multigrid solvers (see ICASE Report No. 88-73). Our work is related to the extension of the previous analysis to the case of more than one dimension. The convergence rate was proven to be independent of both k (the number of subdomains) and N (the degree of the polynomials) in the case of a one-dimensional problem; in two dimensions the convergence rate is still independent of k but scales like $\sqrt{N}$. Collaboration was with R. Munoz, A. T. Patera, and E. Rønquist.

- High-order Lagrangian decoupling methods. After the reports (89-53) and (89-54) we have analyzed the extension of this strategy to the case of compressible flows. The design of the scheme is the same but more then one characteristic must be considered. The potential for significant saving holds also in this case. This research is in collaboration with M. Macaraeg and C. Streett (Fluid Dynamics Division, LaRC).

- Approximation of fourth-order problems with C. Bernardi and G. Coppoletta. This work is related to the extension of the ideas presented in ICASE Report No. 89-36 to problems in more than one dimension and more than one element.

Dimitri Mavriplis

Work is continuing on the use of unstructured triangular meshes for solving turbulent viscous flow problems about arbitrary configurations in two-dimensions.

The basic scheme for solving the Navier-Stokes equations on an unstructured mesh has previously been developed demonstrated for laminar flows about simple geometries (AIAA Paper 89-120, January 1989); thus, the major research effort has concentrated on the generation and adaptive refinement of triangular meshes suitable for high-Reynolds-number calculations, and the incorporation of a turbulence model for use on constructured meshes.

For high-Reynolds number flows, extremely high normal gradients occur in the boundary layer and wake regions. The efficient resolution of such flows requires the use of a grid with very high aspect ratio elements in these viscous regions. In order to generate a suitable unstructured mesh, a distribution of points which is closely packed in the normal directions and sparsely spaced in the streamwise direction must be employed. This type of mesh point distribution is obtained by generating a structured mesh, using a hyperbolic mesh generation,

around each local geometry component, and then considering the union of all the points of these overlapping structured meshes, which lie in the flow field.

The unstructured mesh is then formed by joining these points together in an appropriate manner to form a set of non overlapping triangles. For inviscid flows, a Delaunay triangulation algorithm has previously been employed. However, since this algorithm has the property of minimizing triangle aspect ratios, it has been modified to allow the generation of highly stretched elements. This has been accomplished by a local mapping function which maps the physical space into a locally stretched space in which the Delaunay triangulation process is then effected.

Adaptive mesh enrichment is accomplished by adding points to the existing mesh in regions of large discretization errors, and locally restructuring the mesh by use of a Delaunay algorithm in the mapped space.

The present approach of using a fully unstructured mesh throughout the viscous and inviscid regions of flow as opposed to employing a hybrid structured-unstructured mesh has been pursued in the interest of obtaining a more general meshing strategy which may easily accommodate incremental adaptivity as opposed to remeshing throughout all regions of the flow field.

An algebraic turbulence model has also been developed for use on unstructured meshes. Based on the Baldwin-Lomax model, this algebraic model makes use of background structured mesh lines. At each time step within the solution of the flow on the global unstructured mesh, the current flow variables are interpolated onto to a series of local structured meshes, and the resulting eddy viscosity values are interpolated back onto the unstructured mesh.

The present method has been used to compute turbulent flow in the transonic regime over a two-element airfoil system. A good prediction of the surface pressure distribution obtained from wind tunnel experiments has been observed.

Future work is aimed at applying this method to more complex configurations for internal as well as external flows, and extending the flow solver to three-dimensions.

Piyush Mehrotra and John Van Rosendale

Distributed memory machines have the potential to supply large amounts of computing power but have proven awkward to the program. The problem seems to be that the message passing languages currently available for such machines directly reflect the underlying hardware. Experience has shown that the message passing version of a program is often five to ten times longer than the sequential version. In addition, the intricate "message plumbing" makes programs difficult to debug, and "hard wires" all algorithm choices, preventing easy experimentation with alternate algorithm designs.

In the last six months, we have been designing a programming environment, called Kali, which provides a software layer supporting a global name space on distributed memory architectures. The computation is specified via a set of parallel loops using this global name space exactly as one does on a shared memory architecture. However, the user provides annotations to control aspects of the program which are critical to performance such as data distribution and load balance. The goal here is to acquire the ease of programmability of the shared memory model, while retaining the performance characteristics of nonshared memory architectures.

We are currently studying the efficacy of this approach using a Fortran-like language, KF1 (Kali Fortran 1). KF1 consists of standard Fortran, together with constructs for distributing arrays and specifying parallel loops. We are in the process of programming several large numerical applications in KF1, including a multigrid based algorithm, an ADI algorithm, and an iterative algorithm for unstructured meshes in order to assess the expressive power of these language constructs. Our language constructs seem effective for expressing algorithms with static load balancing. We are studying the design of constructs which enable dynamic load balancing strategies to be expressed in a natural way, but this research is in a preliminary stage.

Kirsten Morris

Robustness of controllers designed using Galerkin methods has been shown, extending earlier work by S. Gibson and T. Banks. Current research projects are (1) the application of distributed sensors to digital control of flexible structures, (2) the role of passivity in control of flexible structures, and (3) active control of acoustic noise.

Tobias B. Orloff

Work began on developing a high quality rendering algorithm based on the radiosity method. The algorithm is similar to previous progressive radiosity algorithms except for the following improvements:

1. At each iteration vertex radiosities are computed using a modified scan line approach, thus eliminating the quadratic cost associated with a ray tracing computation of vortex radiosities.

2. At each iteration the scene is subdivided on the fly as needed, thus there is essentially no storage overhead associated with saving the entire subdivided scene at once.

3. No assumptions are made concerning vertex adjacency information in the database. This allows the algorithm to proceed without any costly pre-processing for scenes without vertex adjacency information.

4. The algorithm works for any geometry that can be subdivided (to arbitrary precision) into triangles (e.g., NURBS). Because of 2) we can do the subdivision on the fly and do not have to maintain a subdivision of the entire scene.

5. The algorithm automatically anti-aliases with each iteration (using a form of sub-pixel jittering in the view).

Tobias B. Orloff and Thomas W. Crockett

Research continued on parallel three-dimensional triangle renderer. An initial version of the renderer running on the iPSC/2 hypercube successfully demonstrated the ability to exploit both object-level and pixel-level parallelism without incurring excessive overheads. Rendering rates in excess of 12,000 Gouraud-shaded triangles per second for complex scenes bolster our estimates that next-generation parallel computers will be able to render scenes at rates of one million triangles per second, or more.

Yuh Roung Ou

Recent advances in supercomputers for simulation of fluid flow have created new challenges for the development of new mathematical methods and models for complex flows. Analytical research is under way to improve our knowledge of the dynamics of the Navier-Stokes equations describing the fluid flow.

We consider the regularized form of Navier-Stokes equations for a viscous incompressible fluid by adding a fourth order operator (Laplacian square) with an artificial dissipation term ϵ. We have shown that the solutions of the regularized system converge to the solution of the conventional Navier-Stokes system as $\epsilon \to 0$. We establish the existence of a global attractor Λ_ϵ for the regularized system for each ϵ. (This attractor will contain all the stationary, time periodic and quasiperiodic solutions.) Then we show these attractors Λ_ϵ are upper semicontinuous at $\epsilon = 0$. That allows us to establish the convergence of the attractor Λ_ϵ to the attractor Λ of the conventional Navier-Stokes equations as $\epsilon \to 0$. An ICASE report describing this work is being prepared.

In collaboration with H. T. Banks and J. Burns, analytical and computational research on the active control of flows is being undertaken. Work has focused primarily on the control

of separated flows by using forced unsteadiness. The analysis will involve a computational solution for flow around an airfoil/spoiler-like configuration with separated regions. A two-dimensional potential flow model is formulated using surface singularity distributions (i.e., panel method) coupled with the zero normal flow boundary condition. The main goal here is to achieve the desired surface pressure modifications by introducing locally unsteady vorticity.

Merrell L. Patrick and Mark Jones

Development of algorithms for solving the generalized eigenvalue problem is continuing. An eigensolver, LANZ, based on the Lanczos method has been implemented and tested on the Convex, Cray Y-MP, and Cray 2 computers. Performance of LANZ has been compared with that of the eigensolver module, EIG, in the NASA Langley structural analysis testbed system running on the Convex and Cray 2 systems. For all problems tested, the performance of LANZ is substantially superior to that of the EIG module.

Our approach required the development of a routine for solving indefinite linear systems of equations. Such systems arise because shifting is required to improve convergence rates of the Lanczos iterations. A shifting strategy was developed for optimal performance of the algorithm and tested for robustness. A routine based on the Bunch-Kaufman algorithm for solving indefinite systems was implemented and shown to perform better than a LINPACK algorithm based on LU factorization.

A parallel version of LANZ is being implemented using the Force language due to Harry Jordan and it's performance compared to that of the non-Force version. Various levels of loop unrolling are being tested for improving the performance of vector and parallel versions of the program. Block Lanczos is also being studied as an alternative for improving the parallel performance of LANZ.

This work is being done in collaboration with O. Storaasli (Structural Mechanics Division, LaRC).

Merrell L. Patrick and Terrence W. Pratt

Methods for porting existing FORTRAN based applications codes to new parallel architectures are the focus of this study. The NASA LAURA code (Langley Aerothermodynamic Upwind Relaxation Algorithm), developed by P. Gnoffo (Space Systems Division, LaRC) is being studied as a test case. We are looking at both spatial and temporal partitioning methods for parallel execution of this code on various architectures, including the Intel iPSC/2. An execution time profile of the code has been obtained and an analysis of data partitioning

and data flow from subroutine to subroutine is being carried out.

Douglas Peterson

Two Sun 3/160 systems have been installed. One system is ICASE.EDU, which handles routing of incoming mail, provides nameserver functions, and serves as a YP master server. The second 3/160 has been installed as a file and print server for the business office workstations and functions as a YP slave server. Sun OS 4.0.3 is installed as the operating system on these machines and their diskless clients.

Six Sun SPARCstation I's have been installed. Two of them are diskful machines, each of which functions as a YP slave server and is a file server for two diskless SPARCstations. With the exception of applications written in FORTRAN, all local applications have been installed on the SPARC's.

A second 892MB disk has been added to one of the 3/180 file servers, providing a total on-line storage capacity of approximately 3GB.

The operating system for this file server and its diskless clients has been upgraded to Sun OS 4.0.3. The memory for those 3/50 workstations which run 4.0.3 has been upgraded to 8MB.

An Exabyte 8mm tape drive has been installed to provide backup capacity for this disk space.

Timothy N. Phillips

Spectral domain decomposition methods are being developed for solving problems in computational fluid dynamics. For the Navier-Stokes equations, a stream function formulation is used to satisfy mass identically. A conforming spectral collocation strategy is devised (ICASE Report 89-60) so that the resulting approximation is continuous across subdomain interfaces. Work is in progress to solve for the flow through a contraction for moderate values of the Reynolds number. Preliminary results indicate the appearance of a vortex downstream of the constriction for a Reynolds number of around 200.

Time-stepping methods for the solution of transient problems in non-Newtonian fluid mechanics are being investigated. The aim here is to solve a wide range of flow problems that are of industrial importance using the spectral domain decomposition methods we have developed.

In collaboration with T. A. Zang (Fluid Mechanics Division, LaRC) work is progressing on the development of efficient preconditioners for spectral multigrid methods for three-dimensional Poisson problems. An analysis of line relaxation schemes has been performed

and numerical experiments confirm the theoretical predictions.

Finally, some theoretical results (ICASE Report 89-65) relating the coefficients of derivatives of series expansions in Jacobi polynomials in terms of the coefficients of the original expansion have been derived.

Ugo Piomelli

Research has been conducted to study the accuracy of large-eddy simulation (LES) of transitional flows by performing calculations of incompressible transitional flat-plate boundary layer flow and plane channel flow with various residual stress models; the LES results are compared with those of direct simulations. Specifically, this study has attempted to: 1) determine whether LES calculations allow accurate prediction not only of statistical quantities, but also of local effects (evolution of shear layers etc.); 2) investigate whether the inclusion of energy-producing terms in the residual stress model is required to predict with satisfactory accuracy the transition process; 3) study whether any correlation exists between large-scale quantities such as the large-scale strain rate, vorticity or Reynolds stress, and subgrid scale activity; 4) determine whether the Reynolds number significantly affects the accuracy of the residual stress model.

Terrence W. Pratt

PISCES 3 is a parallel programming environment for scientific and engineering applications that is being implemented for both shared and distributed memory parallel computers. The goal is to provide a convenient parallel programming environment that allows large applications codes to be run on various parallel computer architectures without reprogramming.

PISCES 3 is based on the PISCES 2 environment that was implemented on the 20-processor Flexible FLEX/32 system in 1987. PISCES 3 retains the major elements of the PISCES 2 system, including the user interface, tasks, asynchronous message passing, forces, shared variables and the FORTRAN extensions to provide access to these facilities. In addition, PISCES 3 will provide:

- A C interface to the PISCES virtual machine, so that applications program may use C, FORTRAN, or a combination of both languages.
- A new "loosely synchronous" communication style, based on the use of "stencils" to define local communication topologies.

- Direct read/write access to arbitrary portions of large data arrays stored on multiple parallel disks.

- Implementation of PISCES 3 is currently underway for the Intel iPSC/2.

Peter Protzel

Together with D. Palumbo (Information Systems Division, LaRC), we are continuing our investigation of the fault-tolerance characteristics of certain Artificial Neural Networks (ANNs) and of the applicability of ANNs in the area of real-time control and communication systems. In computer simulations, we have implemented a special type of ANN that can be used to obtain good solutions to certain optimization problems and we used two classical optimization problems, the Traveling Salesman Problem (TSP) and the Assignment Problem (AP), as initial model problems for our studies. We had to define a suitable performance measure for a large-scale simulation experiment in order to quantify the performance degradation after "injection" of up to 13 simultaneous faults in networks with up to 900 "neurons." The results demonstrate not only the extreme robustness of these networks, but also show that the network treats a fault as an additional constraint to the problem and still converges to the best solution possible under that constraint. These results will be presented at the next International Joint Conference on Neural Networks IJCNN-90 in Washington, D.C., and are documented in detail in a forthcoming ICASE Report.

The extreme fault-tolerance, which is "built-in" and does not require redundant resources, together with the speed when implemented in hardware make this type of ANN interesting for real-time control problems with high reliability requirements. However, not all control problems can be expressed as optimization problems in a way that is suitable for the ANN approach, and the identification of functions within a flight control and/or computer communication system that are implementable as an ANN is part of our project. One such function that is currently under investigation is the real-time task allocation with load balancing for a fault-tolerant, distributed computer system, which requires the fast and reliable reallocation of all its tasks after a failure of one of the processors. Another interesting application area is the on-line error correction of codes by an associative memory with analog decoding, and the simulation and evaluation of a high order ANN is planned in collaboration with C. Jeffries from Clemson University.

Joel Saltz

The inner loop of Krylov space solvers preconditioned with incompletely factored matrices involves computation of upper and lower sparse triangular systems. These triangular matrix solutions can constitute an appreciable percentage of the operations required in the iterative portion of preconditioned Krylov space algorithms. It is consequently essential to efficiently compute these sparse triangular solves. We are performing the optimizations required to vectorize and parallelize these operations on an eight processor Cray Y/MP. We will attempt to model the Cray Y/MP performance so that we can extend our results to deal with future more highly parallel vector machines. For purposes of perspective, we are also performing the rather straightforward task of parallelizing the rest of the Krylov solver code. This work is being done in collaboration with V. Venkatakrishnan (Analytical Services & Materials, Inc.).

Jeffrey S. Scroggs and Paul Saylor

This is a preliminary investigation into combining asymptotic analysis and waveform relaxation to form a numerical method with both high accuracy and parallel capability. Since waveform methods easily exploit medium-grain to small-grain parallelism, the focus will be on obtaining accuracy.

Waveform relaxation is a technique developed by electrical engineers for the solution of the equations of circuit simulation. In its application to CFD, the method of lines yields a system of ordinary differential equations by discretizing the spatial derivatives. The waveform technique is to decouple the ODEs, solve each equation, then employ functional iteration to obtain a solution to the system. Waveform relaxation has two advantages. One is that different time steps can be used for different components; the other is that the decoupling makes it trivial to distribute the system among multi-processors for a parallel solution.

The role of asymptotic analysis is to adapt waveform relaxation to the special requirements of CFD. As an example, asymptotic analysis may be used to formulate a conservative scheme in the presence of shocks. In addition, asymptotic analysis may be used to resolve the physically relevant and diverse scales that arise when simulating flow with smooth regions interspersed with boundary layers and shocks.

Sharon S. Seddougui

Work is being continued to investigate the effect of significant wall cooling on the stability of the compressible triple-deck structure for a three-dimensional boundary layer. This study is jointly being undertaken with F. Smith. We show that a new flow structure can occur when

the wall is cooled sufficiently. Unstable modes, with growth rates which increase as the wall is cooled further, have been found for two-dimensional and three-dimensional disturbances, for both subsonic and supersonic flows. This work is being prepared for an ICASE Report.

The nonlinear breakdown of wavy Görtler vortices is jointly being investigated with Andrew Bassom. This work is the nonlinear extension of the work of Hall and Seddougui (J. Fluid Mech., July 1989, **204**, 405-419) who show that this breakdown of small wavelength Görtler vortices is confined to the shear layers which trap the vortices and will produce wavy vortex boundaries in the streamwise direction. In the course of the present work, additional eigenmodes were found to those obtained by Hall and Seddougui. These are presented in a forthcoming ICASE Report. Weakly nonlinear solutions have been obtained as well as fully nonlinear solutions. We are currently investigating the effect of increasing the size of the disturbance amplitude on the wavenumber and frequency of the imposed disturbance.

Chi-Wang Shu

We are investigating efficient implementations of ENO (essentially non-oscillatory) finite difference schemes for 2D and 3D compressible Euler or Navier-Stokes equations. Particular attention is paid to the practical issues such as vectorization and storage requirements. We test the schemes on a variety of problems, including 2D and 3D homogeneous turbulence, shear flows and shock interaction with turbulence, for which the existence of both discontinuities and fine structures in smooth regions makes non-oscillatory high order methods very desirable. This is a joint project with T. Zang and G. Erlebacher (Fluid Mechanics Division, LaRC). There is also a joint work with C. Swanson (Fluid Mechanics Division, LaRC) in using ENO schemes for computing aerodynamic problems.

We are adapting ENO schemes to Hamilton-Jacobi type equations. Preliminary numerical test on 2D Riemann problems gives promising results. The method has a good potential for applications in control theory and other fields. This is a joint project with S. Osher.

We continue in the investigation of ENO spectral methods for shock wave calculations. One-sided filters combined with discontinuous basis functions are being considered. This is a joint project with D. Gottlieb and Wei Cai (Brown University).

Charles G. Speziale

A preliminary compressible second-order closure model for high-speed flows has been developed in collaboration with S. Sarkar for use in connection with the National Aerospace Plane Project. This turbulence model requires the solution of transport equations for the Favre-averaged Reynolds stress tensor and turbulent dissipation rate. At this stage of the

model development, the Reynolds bet flux and the mass flux are modeled by the usual gradient transport hypotheses. A new model for the rapid pressure-strain correlation, which was developed in collaboration with S. Sarkar and T. B. Gatski (Fluid Mechanics Division, LaRC), is incorporated into this Reynolds stress transport model. Work is currently underway with T. B. Gatski (Fluid Mechanics Division, LaRC) on the development of models which are more asymptotically consistent near walls and can account for anisotropies in the lengths scales and dissipation rate. In regard to the latter issue, a modeled tensor dissipation rate transport equation has been developed.

Research has continued on the large-eddy simulation of transitional flows with U. Piomelli, M. Y. Hussaini, and T. A. Zang (Fluid Mechanics Division, LaRC). Large-eddy simulations of the incompressible flat-plate boundary layer have been conducted. Results obtained using a rescaled Smagorinsky model and an RNG based subgrid scale model appear to be promising.

Shlomo Ta'asan

Research continued on efficient multigrid solvers for constraint optimization problems governed by partial differential equations. A new method for treatment of control problems governed by elliptic PDE's has been developed. The case of finite dimensional control has been considered so far. In that case, solution for the full optimization problem was reached with the same cost as solving the constraint equations about 2-3 times. Research is continuing in applying the techniques developed for identification problems in which the parameter space is finite dimensional (and not too large), e.g., impedance tomography.

The same ideas are being considered in the context of aerodynamics design problems where airfoils are to be calculated so as to meet certain design requirements, for example, to obtain a pressure distribution for some flow conditions which is closest to a given pressure distribution. In the course of developing this idea, new Euler solvers are being developed which use DGS relaxation schemes and perform equally well for all Mach numbers.

Another area of research is the development of new computational techniques in elastic-plastic problems. Here a set of non-linear equations which involve also weak dependence of the history of the loading are to be calculated. Our effort is focused on trying to perform most of the computation on coarse levels. Different continuation techniques (in the load parameters) are being tested to obtain ones which are best suited for multigrid algorithms.

A new method for the calculation of several eigenfunctions of elliptic problems has been developed. Its computational complexity is $O(qN)$ where q is the number of eigenfunctions involved and N is the number of unknowns for each eigenfunction. Previously developed algorithms had complexity of $O(q^2N)$, because of the Ritz projection that is needed for such

problems. Our new algorithm also uses a Ritz projection but it is done on the coarsest level so its cost is negligible, reducing the cost of the algorithm to a minimum.

Eitan Tadmor

In ICASE Report No. 89-67 we give a bird's eye view of shock capturing by the spectral viscosity method. Numerical tests with spectral methods for nonlinear conservation laws indicate that the convergence may (and in fact in some cases we prove it must) fail, with or without post-processing of the numerical solution. The failure of convergence in such cases is related to the global nature of spectral methods: once shock discontinuities appear in the solution, the spectral methods pollute unstable Gibbs oscillations over all the computational domain, and the lack of entropy dissipation prevents convergence in these cases. Instead, the Spectral Viscosity method makes use of high frequency-dependent viscosity regularization. Using compensated compactness arguments, we show that this method enforces the convergence of nonlinear spectral approximations without sacrificing their overall spectral accuracy.

In a joint work with B. Perthame, we construct a nonlinear kinetic equation, and prove that it is well-adapted to describe general multidimensional scalar conservation laws. In particular we prove that it is well-posed (*uniformly in* ε - the microscopic scale). We also show that the proposed kinetic equation is equipped with a family of kinetic entropy functions - analogous to Boltzmann's microscopic H-function, such that they recover Krushkov-type entropy inequality on the macroscopic scale. Finally, we prove by both BV compactness arguments in the multidimensional case and by compensated compactness arguments in the one-dimensional case, that the total mass of kinetic particles admits a 'continuum' limit, as it converges strongly with $\varepsilon \downarrow 0$ to the unique entropy solution of the corresponding conservation law.

Hillel Tal-Ezer

Spectral methods are based on projecting the solution on a finite subspace. The criteria for choosing the right subspace are mainly two: 1) accuracy and 2) stability. When the solution is periodic, it is well-known that the appropriate subspace is spanned by the trigonometric functions. It provides high accuracy and reasonable stability conditions. When the solution is nonperiodic, the state of the art is to use the finite polynomial subspace. More precisely, the basis functions are orthogonal polynomials (e.g., Chebyshev, Legendre). This expansion provides high accuracy but, unfortunately, the stability condition is very severe. An heuristic explanation ties this phenomenon to the uneven distribution of the interpo-

lating points; they are denser near the boundaries. In the present research, we suggest a different approximation subspace in order to overcome the severe stability condition. The basis functions are trigonometric functions which depend on a parameter. This parameter is dimension dependent, and we can show that by choosing the right parameter we can get both high accuracy and favorable stability conditions. The time step restriction which results is more like the one we encounter in periodic problems. We continue the research in this direction in collaboration with D. Kosloff (Tel-Aviv University) and we look now at a two parameter family of trigonometric functions which will, hopefully, provide high accuracy for very irregular problems.

Saleh Tanveer

During the period, progress has been made in several areas of fluid dynamics and crystal growth.

Viscous fingering in the Hele-Shaw cell was considered in the case when the thin film effects are included in the dynamic and as well as in the kinematic conditions. An analytic theory valid in the one limit in the parameter space has been advanced that accounts for a new class of selection rules that allow the relative finger width to be between 0 and a half. The finger widths on different branches can be significantly different suggesting that if only one branch is linearly stable, it might be nonlinearly stable as well for a significantly larger threshold amplitude than for the other class of solution found by Mclean & Saffman for simplified boundary conditions that neglect the thin film effects.

With Vidyadhar Mudkavi at Caltech, a cubic Schroedinger equation has been derived that accounts for the amplitude modulation of well known Kelvin waves on a straight vortex filament. The study of these equations can possibly explain the beginnings of a vortex breakdown.

With Dan Meiron at Caltech, an analytical investigation is being carried out on the linear stability of the 2-D dendritic crystal growth problem at arbitrary Peclet number without the assumption of quasi-stationarity usually employed in existing literature.

Eli Turkel

Work is continuing on the multistage central difference scheme for solving flow around aerodynamic bodies. The artificial viscosity has been changed to a matrix valued function. It has been successfully tested for inviscid, viscous laminar and viscous turbulent flows. In particular we have tested the code for three dimensional viscous, turbulent flow about an ONERA M6 wing. Significant improvements have been found through the use of the matrix

valued viscosity.

We have also begun work on converting the central difference scheme into a TVD scheme. We have shown that the present central difference scheme with a fourth order and second order viscosity is almost TVD except for the switches used to determine the location of the shock. By using a different normalization for the second difference of the pressure, we can show that the scalar 1D scheme is TVD.

A new project has been started to analyze the multigrid method for hyperbolic equations. This work is concentrating on the use of multistage techniques to advance the Euler equations to a steady state. Though the multigrid scheme has been used extensively for hyperbolic problems, there is relatively little theory. This work is being pursued in collaboration with Naomi Decker. In particular, we have shown that the multigrid code converges for hypersonic flow around a bump in a channel. We have also shown that increasing the number of iterations on the coarsest meshes enables the code to reach steady state in fewer cycles, though in more computer time. Hence, by using appropriate smoothers and boundary conditions the multigrid code for hyperbolic equations seems to have all the nice features of the code for elliptic equations even for Mach 10 flows. More complicated geometries are presently being investigated.

Bram van Leer

The research effort covered two subjects:

(1) Preconditioning of 2-D Euler residuals by a local matrix, in order to remove the stiffness due to the differences in the wave speeds implied by the Euler equations. It appears to be impossible to bring all wave speeds, regardless of the direction and mode of the wave, up to the same value, by local preconditioning; the variations among the wave speeds, though, may be minimized, e.g., in the least-squares sense. An explicit algorithm based on the least-squares approach gave a marginal improvement in convergence rate for subsonic flow, but this is not the dramatic improvement known from 1-D. Other minimization procedures are presently under investigation.

(2) A multi-dimensional Riemann solver based on only two input states, with C. Rumsey (Fluid Mechanics Division, LaRC). The Riemann solver was developed in the summer of 1988 at ICASE with P. L. Roe (see Semiannual Report April-September 1988), and is now being tested in practice by Rumsey as part of his thesis work. Preliminary results indicate that the Riemann solver does tighten up oblique shocks and shear waves, but, as expected, it is not very robust, and slows down convergence.

REPORTS AND ABSTRACTS

Banks, H. T., R. H. Fabiano, and Y. Wang: *Inverse problem techniques for beams with tip body and time hysteresis damping.* ICASE Report No. 89-22, April 18, 1989, 24 pages. Submitted to Matematica Aplicada e Computacional.

We present a model for a flexible beam with time hysteresis (Boltzmann type viscoelasticity) damping and tip body. A computational method for the estimation of the damping parameters is developed, and theoretical convergence/continuous dependence results are given. An example is represented in which experimental data is used, demonstrating the efficacy of the computational method and the plausibility of the model for predicting response in damped structures.

Hall, Philip and Yibin Fu: *On the Görtler vortex instability mechanism at hypersonic speeds.* ICASE Report No. 89-23, May 10, 1989, 24 pages. Submitted to Theoretical and Computational Fluid Dynamics.

The linear instability of the hypersonic boundary layer on a curved wall is considered. As a starting point the viscosity of the fluid is taken to be a linear function of temperature and real-gas effects are ignored. It is shown that the flow is susceptible to Görtler vortices and that they are trapped in the logarithmically thin adjustment layer in which the temperature of the basic flow changes rapidly to its free stream value. The vortices decay exponentially in both directions away from this layer and are most unstable when their wavelength is comparable with the depth of the adjustment layer. The non-uniqueness of the neutral stability curve associated with incompressible Görtler vortices is shown to disappear at high Mach numbers if the appropriate 'fast' streamwise dependence of the instability is built into the disturbance flow structure. It is shown that in the hypersonic limit wall-cooling has a negligible effect on the stability of a fluid with a given value of the Chapman constant.

Decker, Naomi and John Van Rosendale: *Operator induced multigrid algorithm using semirefinement.* ICASE Report No. 89-24, April 20, 1989, 23 pages. Submitted to Copper Mountain Multigrid Conference.

This paper describes a variant of multigrid based on zebra relaxation, and a new family of restriction/prolongation operators.

Using zebra relaxation in combination with an operator-induced prolongation leads to fast convergence, since the coarse grid can correct all error components. The resulting algorithms are not only fast, but are also "robust," in the sense that the convergence rate is insensitive to the mesh aspect ratio. This is true even though line relaxation is performed in only one directions. Multigrid becomes a direct method if one uses an operator-induced prolongation, together with the "induced" coarse grid operators.

Unfortunately, this approach leads to stencils which double in size on each coarser grid. In this paper, we show how the use of an implicit three point restriction can be used to "factor" these large stencils, in order to retain the usual five or nine point stencils, while still achieving fast convergence. This algorithm achieves a V-cycle convergence rate of 0.03 on

Poisson's equation, using 1.5 zebra sweeps per level, while the convergence rate improves to 0.003 if optimal nine point stencils are used. This paper represents numerical results for two and three dimensional model problems, together with a two level analysis explaining these results.

Hur, N., S. Thangam, and C. G. Speziale: *Numerical study of turbulent secondary flows in curved ducts.* ICASE Report No. 89-25, April 13, 1989, 27 pages. Submitted to J. Fluids Engrg.

The pressure driven, fully-developed turbulent flow of an incompressible viscous fluid in curved ducts of square cross-section is studied numerically by making use of a finite volume method. A nonlinear K-l model is used to represent the turbulence. The results for both straight and curved ducts are presented. For the case of fully-developed turbulent flow in straight ducts, the secondary flow is characterized by an eight-vortex structure for which the computed flowfield is shown to be in good agreement with available experimental data. The introduction of moderate curvature is shown to cause a substantial increase in the strength of the secondary flow and to change the secondary flow pattern to either a double-vortex or a four-vortex configuration.

Kojima, Fumio: *Shape identification technique for a two-dimensional elliptic system by boundary integral equation method.* ICASE Report No. 89-26, April 13, 1989, 22 pages. Submitted to Proc. 5th IFAC Symp. on Control of Distribute Parameter Systems, Perpignan, France.

This paper is concerned with the identification of the geometrical structure of the boundary shape for a two-dimensional boundary value problem. The output least square identification method is considered for estimating partially unknown boundary shapes. A numerical parameter estimation technique using the spline collocation method is proposed.

Middleton, David: *Implementing nested conditional statements in SIMD machines.* ICASE Report 89-27, April 18, 1989, 16 pages.

SIMD computers consist of a very large number of processors executing a common sequence of instructions. Maintaining the full speedup potential of such machines is most sensitive to conditional execution in their programs, regions of code where some *PEs* perform no useful work. Techniques are presented for efficiently implementing nested conditional statements, specifically *if* and *case statements*, in SIMD machines, while adding minimal specialized hardware.

Tanveer, Saleh: *Analytic theory for the determination of velocity and stability of bubbles in a Hele-Shaw cell. Part I: Velocity selection.* ICASE Report No. 89-28, April 25, 1989, 56 pages. To appear in Theoretical and Computational Fluid Dynamics.

An asymptotic theory is presented for the determination of velocity and linear stability of a steady symmetric bubble in a Hele-Shaw cell for small surface tension. The bubble velocity U relative to the fluid velocity at infinity is determined for small surface tension T by determining the leading order transcendentally small correction to the asymptotic series solution. It is found that for any relative bubble velocity U in the interval $(U_c 2)$, solutions exist at a countably infinite set of values of T (which has zero as its limit point) corresponding to the different branches of bubble solutions. U_c decreases monotonically from 2 to 1 as the bubble area increases from 0 to. For a bubble of arbitrarily given size, as solution exists on any given branch with relative bubble velocity U satisfying the relation $2 - U = cT^{2/3}$, where c depends on the branch but is independent of the bubble area. The analytic evidence suggests that there are no solutions for $U > 2$. These results are in agreement with earlier analytical results for a finger. An analytic theory is presented for the determination of the linear stability of the bubble in the limit of zero surface tension. Only the solution branch corresponding to the largest possible U for given surface tension is found to be stable, while all the others are unstable, in accordance with earlier numerical results.

Tanveer, Saleh: *Analytic theory for the determination of velocity and stability of bubbles in a Hele-Shaw cell. Part II: Stability.* ICASE Report No. 89-29, April 25, 1989, 22 pages. To appear in Theoretical and Computational Fluid Dynamics.

Here, we extend the analysis of part I to determine the linear stability of a bubble in a Hele-Shaw cell analytically. Only the solution branch corresponding to largest possible bubble velocity U for given surface tension is found to be stable, while all the others are unstable, in accordance with earlier numerical results.

Middleton, David and Sherryl Tomboulian: *Evaluating local indirect addressing in SIMD processors.* ICASE Report No. 89-30, May 2, 1989, 19 pages.

In the design of parallel computers, there exists a tradeoff between the number and power of individual processors. The single instruction stream, multiple data stream (SIMD) model of parallel computers lies at one extreme of the resulting spectrum. The available hardware resources are devoted to creating the largest possible number of processors, and consequently each individual processor must use the fewest possible resources. Disagreement exists as to whether SIMD processors should be able to generate addresses individually into their local data memory, or all processor should access the same address. We examine the tradeoff between the increased capability and the reduced number of processors that occurs in this single instruction stream, multiple, locally addressed, data (SIMLAD) model. We assemble the factors that affect this design choice, and compare the SIMLAD model with the bare SIMD and the MIMD models.

Tanveer, Saleh: *Analytic theory for the selection of 2-D needle crystal at arbitrary peclet number.* ICASE Report No. 89-31, May 5, 1989, 21 pages. Submitted to Phys. Rev. A.

An accurate analytic theory is presented for the velocity selection of a two dimensional needle crystal for arbitrary Peclet number for small values of the surface tension parameter.

The velocity selection is caused by the effect of transcendentally small terms which are determined by analytic continuation to the complex plane and analysis of nonlinear equations.

The work supports the general conclusion of previous small Peclet number analytical results of other investigators, though there are some discrepancies in details. It also addresses questions raised by a recent investigator on the validity of selection theory owing to assumptions made on shape corrections at large distances from the tip.

Jackson, T. L. and C. E. Grosch: *Inviscid spatial stability of a compressible mixing layer. Part III. Effect of thermodynamics.* ICASE Report No. 89-32, May 7, 1989, 46 pages. Submitted to Journal of Fluid Mechanics

We report the results of a comparative study of the inviscid spatial stability of a parallel compressible mixing layer using various models for the mean flow. The models are (a) the hyperbolic tangent profile for the mean speed and the Crocco relation for the mean temperature, with the Chapman viscosity-temperature relation and a Prandtl number of one; (b) the Lock profile for the mean speed and the Crocco relation for the mean temperature, with the Chapman viscosity-temperature relation and a Prandtl number of one; and (c) the similarity solution for the coupled velocity and temperature equations using the Sutherland viscosity temperature relation and arbitrary but constant Prandtl numbers. The purpose of this study was to determine the sensitivity of the stability characteristics of the compressible mixing layer to the assumed thermodynamic properties of the fluid. It is shown that the qualitative features of the stability characteristics are quite similar for all models but that there are quantitative differences resulting from the difference in the thermodynamic models. In particular, we show that the stability characteristics are sensitive to the value of the Prandtl number.

Tomboulian, Sherryl: *Indirect addressing and load balancing for faster solution to Mandelbrot set on SIMD architectures.* ICASE Report No. 89-33, May 5, 1989, 9 pages. Submitted to Symposium University of South Carolina.

SIMD computers with local indirect addressing allow programs to have qsueues and buffers, making certain kinds of problems much more efficient. In particular we examine a class of problems characterized by computations on data points where the computation is identical, but the convergence rate is data dependent. Normally, in this situation, the algorithm time is governed by the maximum number of iterations required by each point. Using indirect addressing allows a processor to proceed to the next data point when it is done, reducing the overall number of iterations required to approach the mean convergence rate when a sufficiently large problem set is solved. Load balancing techniques can be applied for additional performance improvement.

Simulations of this technique applied to solving Mandelbrot sets indicate significant performance gains.

Hall, Philip and Andrew P. Bassom: *On the interaction of stationary crossflow vortices and Tollmien-Schlichting waves in the boundary layer on a rotating disc.* ICASE Report No. 89-34, April 25, 1989, 39 pages. Submitted to Proc. Roy Soc., Series A.

There are many fluid flows where the onset of transition can be caused by different instability mechanisms which compete among themselves. Here we consider the interactions of two types of instability mode (at an asymptotically large Reynolds number) which can occur in the flow above a rotating disk. [illegible] the interaction between lower branch Tollmien-Schlichting (TS) waves and the upper branch, stationary, inviscid crossflow vortex whose asymptotic structure has been described by Hall (1986). This problem is studied in the context of investigating the effect [illegible] on the stability characteristics of a small TS wave. [illegible] through the modification to the mean flow [illegible] the TS wave is taken [illegible] a nonlinear stationary vortex [illegible] destabilizing effects on the TS wave and the nature of [illegible] the orientation of this latter instability. Further, we consider the problem with a [illegible] wave, whose size is chosen so as to ensure that this mode is nonlinear [illegible]. An amplitude equation for the evolution of the TS wave is derived which admits [illegible] corresponding to finite amplitude, stable, traveling waves.

Mavriplis, Dimitri: *Zonal multigrid solution of compressible flow problems on unstructured and adaptive meshes*. ICASE Report No. 89-35, May 1, 1989, 23 pages. Submitted to SIAM Journal on Scientific and Statistical Computing.

This work is concerned with the simultaneous use of adaptive meshing techniques with a multigrid strategy for solving the two dimensional Euler equations in the context of unstructured meshes. To obtain optimal efficiency, methods capable of computing locally improved solutions without recourse to global recalculations are pursued. A method for locally refining an existing unstructured mesh, without regenerating a new global mesh is employed, and the domain is automatically partitioned into refined and unrefined regions. Two multigrid strategies are developed. In the first, time stepping is performed only in the locally refined regions of the domain on the fine mesh levels, and throughout the entire domain on the coarsest mesh levels. In the second method, time stepping is performed on a global fine mesh covering the entire domain, and convergence acceleration is achieved through the use of zonal coarse grid accelerator meshes, which lie under the adaptively refined regions of the global fine mesh. Both schemes are shown to produce similar convergence rates to each other, and also with respect to a previously developed global multigrid algorithm, which performs time stepping throughout the entire domain, on each mesh level. However, the present schemes exhibit higher computational efficiency due to the smaller number of operations on each level.

Bernardi, Christine and Yvon Maday: *Some spectral approximations of monodimensional fourth-order problems*. ICASE Report No. 89-36, May 2, 1989, 78 pages. Submitted to Journal of Approximation Theory.

We propose some spectral type collocation methods well suited for the approximation of fourth order systems. Our model problem is the biharmonic equation, in one dimensional and in two dimensions when the boundary conditions are periodic in one direction. It is proved that the standard Gauss Lobatto nodes are not the best choice for the collocation points. Then, we propose a new set of nodes related to some generalized Gauss type quadrature formulas. We provide a complete analysis of these formulas including some new issues about

the asymptotic behaviour of the weights and we apply these results to the analysis of the collocation method.

Jones, Mark T. and Merrell L. Patrick: *Bunch-Kaufman factorization for real symmetric indefinite banded matrices.* ICASE Report No. 89-37, May 20, 1989, 13 pages. Submitted to Journal of Approximation Theory.

The Bunch-Kaufman algorithm for factoring symmetric indefinite matrices has been rejected for banded matrices because it destroys the banded structure of the matrix. Herein, it is shown that for a subclass of real symmetric matrices which arise in solving the generalized eigenvalue problem using Lanczos's method, the Bunch-Kaufman algorithm does not result in major destruction of the bandwidth. Space time complexities of the algorithm are given and used to show that the Bunch-Kaufman algorithm is a significant improvement over LU factorization.

Jackson, T. L. and C. E. Grosch: *Absolute/convective instabilities and the convective Mach number in a compressible mixing layer.* ICASE Report No. 89-38, June 14, 1989, 21 pages. Submitted to Physics of Fluids.

In this paper we consider two aspects of the stability of a compressible mixing layer: Absolute/Convective instability and the convective Mach number. We show that, for Mach numbers less than one, the compressible mixing layer is convectively unstable unless there is an appreciable amount of backflow. We also present a rigorous derivation of a convective Mach number based on linear stability theory for the flow of a multi-species gas in a mixing layer. Our result is compared with the heuristic definitions of others and to selected experimental results.

Lakin, William D. and Raymond G. Kvaternik: *An integrating matrix formulation for buckling of rotating beams including the effects of concentrated masses.* ICASE Report No. 89-39, May 22, 1989, 28 pages. To appear in Int. J. Mechanical Sciences.

This paper extends the integrating matrix technique of computational mechanics to include the effects of concentrated masses. The stability of a flexible rotating beam with discrete masses is analyzed to determine the critical rotational speeds for buckling in the inplane and out-of-lane directions. In this problem, the beam is subject to compressive centrifugal forces arising from steady rotation about an axis which does not pass through the clamped end of the beam. To determine the eigenvalues from which stability is assessed, the differential equations of motion are solved numerically be combining the extended integrating matrix method with an eigenanalysis. Stability boundaries for a discrete mass representation of a uniform beam are shown to asymptotically approach the stability boundaries for the corresponding continuous mass beam as the number of concentrated masses is increased. An error in the literature is also noted for the discrete mass problem concerning the behavior of the critical rotational speed for inplane buckling as the radius of rotation of the clamped end of the beam is reduced.

Naik, Vijay K. and Merrell L. Patrick: *Data traffic reduction schemes for Cholesky factorization on asynchronous multiprocessor systems.* ICASE Report No. 89-40, June 1, 1989, 29 pages. Proceedings of ACM 1989 International Conference on Supercomputing, June 5-9, 1989, Crete, Greece.

Communication requirements of Cholesky factorization of dense and sparse symmetric, positive definite matrices are analyzed. The communication requirement is characterized by the data traffic generated on multiprocessor systems with local and shared memory.

Lower bound proofs are given to show that when the load is uniformly distributed the data traffic associated with factoring an nxn dense matrix using $n^\alpha, \alpha \leq 2$, processors is $\Omega(n^{2+\alpha/2})$. For an nxn sparse matrices representing a $\sqrt{n}x\sqrt{n}$ regular grid graph the data traffic shown to be $\Omega(n^{1+\alpha/2}), \alpha \leq 1$.

Partitioning schemes that are variations of block assignment scheme are described and it is shown that the data traffic generated by these schemes are asymptotically optimal. The schemes allow efficient use of up to $0(n^2)$ processors in the dense case and up to $0(n)$ processors in the sparse case before the total data traffic reaches the maximum value of $0(n^3)$ and $0(n^{3/2})$, respectively. It is shown that the block based partitioning schemes allow a better utilization of the data accessed from shared memory and thus reduce the data traffic than those based on column-wise wrap around assignment schemes.

Mehrotra, Piyush and John Van Rosendale: *Parallel language constructs for tensor product computations on loosely coupled architectures.* ICASE Report No. 89-41, June 2, 1989, 27 pages. Supercomputing 1989 Conference.

Distributed memory architectures offer high levels of performance and flexibility, but have proven awkward to program. Current languages for nonshared memory architectures provide a relatively low level programming environment, and are poorly suited to modular programming, or the construction of libraries of compatible routines. This paper describes a set of language primitives designed to allow the specification of parallel numerical algorithms at a higher level.

We focus particularly on tensor product array computations, a simple but important class of numerical algorithms. We consider first the problem of programming one dimensional "kernel" routines, such as parallel tridiagonal solvers, and after that look at how such parallel kernels can be combined to form parallel tensor product algorithms

Landriani, G. Sacchi, and H. Vandeven: *A multidomain spectral collocation method for the Stokes problem.* ICASE Report No. 89-42, June 5, 1989, 31 pages. Submitted to Numerische Mathematica.

We propose a multidomain spectral collocation scheme for the approximation of the two-dimensional Stokes problem. We show that the discrete velocity vector field is exactly divergence free and we prove error estimates both for the velocity and the pressure.

Speziale, C. G., T. B. Gatski and N. Mac Giolla Mhuiris: *A critical comparison of turbulence models for homogeneous shear flows in a rotating frame.* ICASE Report No. 89-43, June 5, 1989, 23 pages. Submitted to Seventh Symposium on Turbulent Shear Flows (Stanford University, August 21-23, 1989).

A variety of turbulence models, including five second-order closures and four two-equation models, are tested for the problem of homogeneous turbulent shear flow in a rotating frame. The model predictions for the time evolution of the turbulent kinetic energy and dissipation rate, as well as those for the equilibrium states, are compared with the results of physical and numerical experiments. Most of the two-equation models predict the same results for all rotation rates in which there is an exponential time growth of the turbulent kinetic energy and dissipation rate. The second-order closures are qualitatively superior since, consistent with physical and numerical experiments, they only predict this type of unstable flow for intermediate rotation rates in the range $-0.1 \leq \Omega \backslash S \leq 0.6$. For rotation rates outside this range, there is an exchange of stabilities with a solution whose kinetic energy and dissipation rate decay with time. Although the second-order closures are superior to the two-equation models, there are still problems with the quantitative accuracy of their predictions.

Banks, H. T., Fumio Kojima, and W. P. Winfree: *Boundary estimation problems arising in thermal tomography.* ICASE Report No. 89-44, November 13, 1989, 42 pages. Submitted to Inverse Problems.

Problems on the identification of two-dimensional spatial domains arising in the detection and characterization of structural flaws in materials are considered. For a thermal diffusion system with external boundary input, observations of the temperature on the surface are used in a output least square approach. Parameter estimation techniques based on the "method of mappings" are discussed and approximation schemes are developed based on a finite element Galerkin approach. Theoretical convergence results for computational techniques are given and the results are applied to experimental data for the identification of flaws in thermal testing of materials.

Carter, Richard: *Numerical optimization in Hilbert space using inexact function and gradient evaluations.* ICASE Report No. 89-45, June 5, 1989, 24 pages. Submitted to SIAM Journal on Control and Optimization.

Trust region algorithms provide a robust iterative technique for solving nonconvex unconstrained optimization problems, but in may instances it is prohibitively expensive to compute high accuracy function and gradient values for the method. Of particular interest are inverse and parameter estimation problems, since function and gradient evaluations involve numerically solving large systems of differential equations.

We present global convergence theory for trust region algorithms in which neither function nor gradient values are known exactly. The theory is formulated in a Hilbert space setting so that it can be applied to variational problems as well as the finite dimensional problems normally seen in trust region literature. The conditions concerning allowable error are remarkably relaxed: relative errors in the gradient values of 0.5 or more are allowed by the theory. One form of the gradient error condition is automatically satisfied if the error

is orthogonal to the gradient approximation. A technique for estimating gradient error and improving the approximation is also presented.

Carter, Richard: *Numerical experience with a class of algorithms for nonlinear optimization using inexact function and gradient information.* ICASE Report No. 89-46, June 10, 1989, 24 pages. Submitted to Mathematics of Computation.

For optimization problems associated with engineering design, parameter estimation, image reconstruction, and other optimization/simulation applications, low accuracy function and gradient values are frequently much less expensive to obtain than high accuracy values. We investigate the computational performance of trust region methods for nonlinear optimization when high accuracy evaluations are unavailable or prohibitively expensive, and confirm earlier theoretical predictions than the algorithm is convergent even with relative gradient errors of 0.5 or more. The proper choice of the amount of accuracy to use in function and gradient evaluations can result in orders-of-magnitude savings in computational cost.

Hall, Philip and F. T. Smith: *Near-planar TS waves and longitudinal vortices in channel flow: Nonlinear interaction and streaks.* ICASE Report No. 89-47, June 6, 1989, 39 pages. Submitted to Journal of Fluid Mechanics.

The nonlinear interaction between planar or near-planar Tollmien-Schlichting waves and longitudinal vortices induced or input, is considered theoretically for channel flows at high Reynolds numbers. Several kinds of nonlinear interaction, dependent on the input amplitudes and wavenumbers or on previously occurring interactions, are found and are inter-related. The first, Type a, is studied the most here and it usually produces spanwise focusing of both the wave and the vortex motion, within a finite scaled time, along with enhancement of both their amplitudes. This then points to the nonlinear interaction Type b where new interactive effects come into force to drive the wave and the vortex nonlinearly. Types c,d correspond to still higher amplitudes, with c being related to b, while d is connected with a larger-scale interaction e studied in an allied paper. Both c,d are subsets of the full three-dimensional triple-deck-like interaction, f. The strongest nonlinear interactions are those of d,e,f since they alter the mean-flow profile substantially, i.e., by an 0(1) relative amount. All the types of nonlinear interaction however can result in the formation of streak-like responses in the sense of spanwise concentrations of vorticity and wave amplitude.

Bernardi, Christine, Vivette Girault, and Laurence Halpern: *Variational formulation for a nonlinear elliptic equation in a three-dimensional exterior domain.* ICASE Report No. 89-48, July 11, 1989, 15 pages. Submitted to Nonlinear Analysis JMA, July 1989.

We obtain an existence result for a nonlinear second-order equation in an exterior domain of $I\!R^3$. The proof relies on a variational in weighted Sobolev spaces.

Geer, James F. and Carl M. Andersen: *A hybrid-perturbation-Galerkin method for differential equations containing a parameter.* ICASE Report No. 89-49, June 20, 1989, 22 pages. Accepted to Applied Mechanics Review.

A two-step hybrid perturbation-Galerkin method to solve a variety of differential equations which involve a parameter is presented and discussed. The method consists of: (1) the use of a perturbation method to determine the asymptotic expansion of the solution about one or more values of the parameter; and (2) the use of some of the perturbation coefficient functions as trial functions in the classical Bubnov-Galerkin method. This hybrid method has the potential of overcoming some of the drawbacks of the perturbation method and the Bubnov-Galerkin method when they are applied by themselves, while combining some of the good features of both. The proposed method is illustrated first with a simple linear two-point boundary value problem and is then applied to a nonlinear two-point boundary value problem in lubrication theory. The results obtained from the hybrid method are compared with approximate solutions obtained by purely numerical methods. Some general features of the method, as well as some special tips for its implementation, are discussed. A survey of some current research application areas is presented and its degree of applicability to broader problem areas is discussed.

Seddougui, Sharon: *A nonlinear investigation of the stationary mode of instability of the three-dimensional compressible boundary layer due to a rotating disc.* ICASE Report No. 89-50, June 21, 1989, 29 pages. The Quarterly Journal of Mechanics and Applied Mathematics.

This work investigates the effects of compressibility on a stationary mode of instability of the three-dimensional boundary layer due to a rotating disc. The aim is to determine whether this mode will be important in the finite amplitude destabilization of the boundary layer. This stationary mode is characterized by the effective velocity profile having zero shear stress at the wall. Triple-deck solutions are presented for an adiabatic wall and an isothermal wall. It is found that this stationary mode is only possible over a finite range of Mach numbers. Asymptotic solutions are obtained which describe the structure of the wavenumber and the orientation of these modes as functions of the local Mach number. The effects of nonlinearity are investigated allowing the finite amplitude growth of a disturbance close to the neutral location to be described. The results are compared with the incompressible results of P. Hall (Proc. R. Soc. Lond., A406, 93-106 (1986)) and S. O. MacKerrell (Proc. R. Soc. Lond., A413, 497-513 (1987)).

Maestrello, L. and L. Ting: *Optimum shape of a blunt forebody in hypersonic flow.* ICASE Report No. 89-51, November 27, 1989, 21 pages. To be submitted to AIAA Journal.

The optimum shape of a blunt forebody attached to a symmetric wedge or cone is determined. The length of the forebody, its semi-thickness or base radius, the nose radius and the radius of the fillet joining the forebody to the wedge or cone are specified. The optimum shape is composed of simple curves. Thus experimental models can be built readily to investigate the utilization of aerodynamic heating for boundary layer control. The optimum shape based on the modified Newtonian theory can also serve as the preliminary shape for the numerical solution of the optimum shape using the governing equations for a compressible inviscid or viscous flow.

Fatemi, Emad, Jerome Joseph, and Stanley Osher: *Solution of the hydrodynamic device model using high-order non-oscillatory shock capturing algorithms.* ICASE Report No. 89-52, July 1, 1989, 71 pages. Submitted to IEEE Transactions on Computer Audio Design of Integrated Systems and Circuits.

A micron $n^+ - n - n^+$ silicon diode is simulated via the hydrodynamic model for carrier transport. The numerical algorithms employed are for the non-steady case, and limiting process is used to reach steady state. The novelty of our simulation lies in the shock capturing algorithms employed, and indeed shocks, or very rapid transition regimes, are observed in the transient case for the coupled system, consisting of the potential equation and the conservation equations describing charge, momentum, and energy transfer for the electron carriers. These algorithms, termed essentially non-oscillatory, have been successfully applied in other contexts to model the flow in gas dynamics, magnetohydrodynamics and other physical situations in involving the conservation laws of fluid mechanics. The method here is first order in time, but the use of small time steps allows for good accu acy. Runge-Kutta methods allow one to achieve higher accuracy in time if desired. The spatial accuracy is of high order in regions of smoothness.

Osher, Stanley: *The nonconvex multi-dimensional Riemann problem for Hamilton-Jacobi equations.* ICASE Report No. 89-53, July 13, 1989, 10 pages. Submitted SIAM Journal on Analysis.

We present simple inequalities for the Riemann problem for a Hamilton-Jacobi equation in N space dimension when neither the initial data nor the Hamiltonian need be convex (or concave). The initial data is globally continuous, affine in each orthant, with a possible jump in normal derivative across each coordinate plane, $x_i = 0$. The inequalities become equalities wherever a "maxmin" equals a "minmax" and thus an exact closed form solution to this problem is then obtained.

Berryman, Harry, Joel Saltz, William Gropp, and Ravi Mirchandaney: *Krylov methods preconditioned with incompletely factored matrices on the CM-2.* ICASE Report No. 89-54, December 21, 1989, 11 pages. To appear in Journal of Parallel and Distributed Computing.

In the work presented here, we measured the performance of the components key iterative kernel of a preconditioned Krylov space iterative linear system solver. In some sense, these numbers can be regarded as best case timings for these kernels. We timed sweeps over meshes, sparse triangular solves, and inner products on a large three dimensional model problem over a cube shaped domain discretized with a seven point template.

The performance of the CM-2 is highly dependent on the use of very specialized programs. These programs mapped a regular problem domain onto the processor topology in a careful manner and used the optimized local NEWS communications network. We also document rather dramatic deterioration in performance when these ideal conditions no longer apply. A synthetic workload generator was developed to produce and solve a parameterized family of increasingly irregular problems.

Piomelli, Ugo, Thomas A. Zang, Charles G. Speziale, and M. Y. Hussaini: *On the large-eddy simulation of transitional wall-bounded flows.* ICASE Report No. 89-55, July 28, 1989, 27 pages. Submitted to Physics of Fluids, Series A.

The structure of the subgrid scale fields in plane channel flow has been studied at various stages of the transition process to turbulence. The residual stress and subgrid scale dissipation calculated using velocity fields generated by direct numerical simulations of the Navier-Stokes equations are significantly different from their counterparts in turbulent flows. The subgrid scale dissipation changes sign over extended areas of the channel, indicating energy flow from the small scales to the large scales.

This reversed energy cascade becomes less pronounced at the later stages of transition. Standard residual stress models of the Smagorinsky type are excessively dissipative.

Rescaling the model constant improves the prediction of the total (integrated) subgrid scale dissipation, but not that of the local one. Despite the somewhat excessive dissipation of the rescaled Smagorinsky model, the results of a large eddy simulation of transition of a flat-plate boundary layer compares quite well with those of a direct simulation, and require only a small fraction of the computational effort. The inclusion non-dissipative models, which could lead to further improvements, is proposed.

Maday, Yvon and Einar M. Rønquist: *Optimal error analysis of spectral methods with emphasis on non-constant coefficients and deformed geometries.* ICASE Report No. 89-56, July 14, 1989, 21 pages. Proceedings of the ICOSAMOM meeting 1989.

In this paper we present the numerical analysis of spectral methods when non-constant coefficients appear in the equation, either due to the original statement of the equations or to take into account the deformed geometry. A particular attention is devoted to the optimality of the discretization even for low values of the discretization parameter. The effect of some "overintegration" is also addressed, in order to possibly improve the accuracy of the discretization.

Ho, Lee-Wing, Yvon Maday, Anthony T. Patera, and Einar M. Rønquist: *A high-order Lagrangian-decoupling method for the incompressible Navier-Stokes equations.* ICASE Report No. 89-57, July 14, 1989, 46 pages. Proceedings of the ICOSAMOM meeting 1989.

In this paper we present a high-order Lagrangian-decoupling method for the unsteady convection-diffusion and incompressible Navier-Stokes equations. The method is based upon: Lagrangian variational forms that reduce the convection-diffusion equation to a symmetric initial value problem; implicit high-order backward-differentiation finite-difference schemes for integration along characteristics; finite element or spectral element spatial discretizations; mesh-invariance procedures and high-order explicit time-stepping schemes for deducing function values at convected space-time points. The method improves upon previous finite element characteristic methods through the systematic and efficient extension to high order accuracy, and the introduction of a simple structure-preserving characteristic-foot calculation procedure which is readily implemented on modern architectures. The new method is significantly more efficient than explicit-convection schemes for the Navier-Stokes equations due to the decoupling of the convection and Stokes operators and the attendant increase in temporal stability. Numerous numerical examples are given for the convection-diffusion and Navier-Stokes equations for the particular case of a spectral element spatial discretization.

Speziale, Charles G.: *Discussion of turbulence modeling: Past and future.* ICASE Report No. 89-58, August 1, 1989, 21 pages. Lecture Notes in Physics.

The full text of the discussion paper presented at the *Whither Turbulence Workshop* (Cornell University, March 22-24, 1989) on past and future trends in turbulence modeling is provided. It is argued that Reynolds stress models are likely to remain the preferred approach for technological applications for at least the next few decades. In general agreement with the Launder position paper, it is further argued that among the variety of Reynolds stress models in use, second-order closures constitute by far the most promising approach. However, some needed improvements in the specification of the turbulent length scale are emphasized. The central points of the paper are illustrated by examples from homogeneous turbulence.

Funaro, Daniele and David Gottlieb: *Convergence results for pseudospectral approximations of hyperbolic systems by a penalty type boundary treatment.* ICASE Report No. 89-59, August 1, 1989, 19 pages. Submitted to Mathematics of Computation.

A new method of imposing boundary conditions in the pseudospectral approximation of hyperbolic systems of equations is proposed. It is suggested to collocate the equations, not only at the inner grid points, but also at the boundary points and use the boundary conditions as penalty terms. In the pseudospectral Legendre method with the new boundary treatment, a stability analysis for the case of a constant coefficient hyperbolic system is presented and error estimates are derived.

Phillips, Timothy N. and Andreas Karageorghis: *A conforming spectral collocation strategy for Stokes flow through a channel contraction.* ICASE Report No. 89-60, August 9, 1989, 30 pages. Submitted to Applied Numerical Mathematics.

A spectral collocation method is described for solving the stream function formulation of the Stokes problem in a contraction geometry. The flow region is decomposed into a number of confernal rectangular subregions. A collocation strategy is devised which ensures that the stream function and its normal derivative are continuous across subregion interfaces. An efficient solution procedure based on the capacitance matrice technique is described for solving the spectral collocation equations.

Hussaini, M. Y., C. G. Speziale, and T. A. Zang: *Discussion of "The potential and limitations of direct and large-eddy simulations."* ICASE Report No. 89-61, August 9, 1989, 16 pages. Submitted to Lecture Notes in Physics.

The full text of the discussion paper presented at the *Whither Turbulence Workshop* (Cornell University, March 22-24, 1989) on the potential and limitations of direct and large-eddy simulations is provided. Particular emphasis is placed on discussing the role of numerics and mathematical theory in direct simulations of both compressible and incompressible flows. A

variety of unresolved issues with large-eddy simulations such as their implementation in high-order finite difference codes, problems with defiltering, and modifications to accommodate integrations to solid boundaries are elaborated on.

These as well as other points are discussed in detail along with the authors' views concerning the prospects for future research.

Scroggs, Jeffrey S.: *An iterative method for systems of nonlinear hyperbolic equations.* ICASE Report No. 89-62, August 11, 1989, 12 pages. Submitted to Applied Numerical Analysis.

An iterative algorithm for the efficient solution of systems of nonlinear hyperbolic equations is presented Parallelism is evident at several levels. In the formation of the iteration, the equations are decoupled, thereby providing large grain parallelism. Parallelism may also be exploited within the solves for each equation. Convergence of the iteration is established via a bounding function argument. Experimental results in two-dimensions are presented.

Tanveer, S.: *Analytic theory for the selection of Saffman-Taylor fingers in the presence of thin film effects.* ICASE Report No. 89-63, September 14, 1989, 58 pages. Submitted to Proc. Roy. Society, Series A.

An analytic theory is presented for the width selection of Saffman-Taylor fingers in the presence of thin film effect. In the limit of small capillary number Ca and small gap to width ratio ϵ, *such that* $\epsilon << Ca << 1$, *it is found that fingers with relative width* $\lambda < \frac{1}{2}$ are possible such that $\frac{\lambda^2(1-\lambda)}{(1-2\lambda)} = k\frac{\epsilon}{Ca^{3/2}}$, where the positive constant k depends on the branch of solution and equals 2.776 for the first branch. A fully nonlinear analysis is necessary in this problem even to obtain the correct scaling law. It is also shown how in principle, the selection rule for arbitrary Ca can be obtained.

Banks, H. T. and D. J. Inman: *On damping mechanisms in beams.* ICASE Report No. 89-64, September 14, 1989, 25 pages. Submitted to J. Appl. Mech.

A partial differential equation model of a cantilevered beam with a tip mass at its free end is used to study damping in a composite. Four separate damping mechanisms consisting of air damping, strain rate damping, spatial hysteresis and time hysteresis are considered experimentally. Dynamic tests were performed to produce time histories. The time history data is then used along with an approximate model to form a sequence of least squares problems. The solution of the least squares problem yields the estimated damping coefficients. The resulting experimentally determined analytical model is compared with the time histories via numerical simulation of the dynamic response. The procedure suggested here is compared with a standard modal damping ratio model commonly used in experimental modal analysis.

Karageorghis, A. and T. N. Phillips: *On the coefficients of differentiated expansions of ultraspherical polynomials.* ICASE Report No. 89-65, September 25, 1989, 9 pages. Submitted to Mathematics of Computation.

A formula expressing the coefficients of an expansion of ultraspherical polynomials which has been differentiated an arbitrary number of times in terms of the coefficients of the original expansion is proved. The particular examples of Chebyshev and Legendre polynomials are considered.

Papageorgiou, D. T.: *Linear instability of supersonic plane wakes.* ICASE Report No. 89-66, September 25, 1989, 29 pages. Submitted to Theoretical and Computational Fluid Dynamics.

In this paper we present a theoretical and numerical study of the growth of linear disturbances in the high-Reynolds-number laminar compressible wake behind a flat plate which is aligned with a uniform stream. No ad hoc assumptions are made as to the nature of the undisturbed flow (in contrast to previous investigations) but instead the theory is developed rationally by use of proper wake-profiles which satisfy the steady equations of motion. The initial growth of near wake perturbations is governed by the compressible Rayleigh equation which is studied analytically involved and provide a rational basis for a nonlinear development. The evolution of arbitrary wavelength perturbations is addressed numerically and spatial stability solutions are presented that account for the relative importance of the different physical mechanisms present, such as three-dimensionality, increasing Mach numbers and the nonparallel nature of the mean flow. Our findings indicate that for low enough (subsonic) Mach numbers, there exists a region of absolute instability very close to the trailing-edge with the majority of the wake being convectively unstable. At higher Mach numbers (but still not large - hypersonic) the absolute instability region seems to disappear and the maximum available growth-rates decrease considerably. Three-dimensional perturbations provide the highest spatial growth-rates.

Tadmor, Eitan: *Shock capturing by the spectral viscosity method.* ICASE Report No. 89-67, September 25, 1989, 11 pages. To appear in Proceedings of the ICOSAHOM Meeting, Como, Italy, June 1989.

A main disadvantage of using spectral methods for nonlinear conservation laws lies in the formation of Gibbs phenomenon, once spontaneous shock discontinuities appear in the solution. The global nature of spectral methods then pollutes the unstable Gibbs oscillations overall the computational domain, and the lack of entropy dissipation prevents convergences in these cases. In this paper, we discuss the Spectral Viscosity method, which is based on high frequency-dependent vanishing viscosity regularization of the classical spectral methods. We show that this method enforces the convergence of nonlinear spectral approximations without sacrificing their overall spectral accuracy.

Jackson, T. L., A. K. Kapila, and M. Y. Hussaini: *Convection of a pattern of vorticity through a reacting shock wave.* ICASE Report No. 89-68, September 27, 1989, 31 pages. Submitted to Physics of Fluids, Series A.

The passage of a weak vorticity disturbance through a reactive shock wave, or detonation, is examined by means of a linearized treatment. Of special interest is the effect of chemical heat release on the amplification of vorticity in particular, and on the disturbance pattern

generated downstream of the detonation in general. It is found that the effect of exothermicity is to amplify the retracted waves. The manner in which the imposed disturbance alters the structure of the detonation itself is also discussed.

Jones, Mark T. and Merrell L. Patrick: *The use of Lanczos's method to solve the large generalized symmetric definite eigenvalue problem.* ICASE Report No. 89-69, September 26, 1989, 49 pages.

The generalized eigenvalue problem, $Kx = \lambda Mx$, is of signification practical importance, especially in structural engineering where it arises as the vibration and buckling problems. A new algorithm, LANZ, based on Lanczos's method is developed. LANZ uses a technique called dynamics shifting to improve the efficiency and reliability of the Lanczos algorithm. A new algorithm for solving the tridiagonal matrices that arise when using Lanczos's method is described. A modification of Parlett and Scott's selective orthogonalization algorithm is proposed. Results from an implementation of LANZ on a Convex C-220 show it to be superior to a subspace iteration code.

Robert G. Voigt: *Requirements of multidisciplinary design of aerospace vehicles on high performance computers.* ICASE Report No. 89-70, September 26, 1989, 9 pages. Proceedings of the NATO Advanced Research Workshop on Supercomputing.

The design of aerospace vehicles is becoming increasingly complex as the various contributing disciplines and physical components become more tightly coupled. This coupling leads to computational problems that will be tractable only if significant advances in high performance computing systems are made. In this paper we discuss some of the modeling, algorithmic and software requirements generated by the design problem.

ICASE INTERIM REPORTS

Crockett, Thomas: *File concepts for parallel I/O.* Interim Report No. 7, May 12, 1989, 16 pages. Supercomputing '89, Proceedings, to appear.

The subject of I/O has often been neglected in the design of parallel computer systems, although for many problems I/O rates will limit the speedup attainable. The I/O problem is addressed here by considering the role of files in parallel systems. The notion of parallel files is introduced. Parallel files provide for concurrent access by multiple processes, and utilize parallellism in the I/O system to improve performance. Parallel files can also be used conventionally by sequential problems. A set of standard parallel file organizations is proposed, based on common data partitioning techniques. Implementation strategies for the proposed organizations are suggested, using multiple storage devices. Problem areas are also identified and discussed.

Speziale, Charles G. and Sutanu Sarkar: *A preliminary compressible second-order closure model for high speed flows.* Interim Report No. 8, July 16, 1989, 6 pages.

A preliminary version of a compressible second-order closure model that has been developed in connection with the National Aero-Space Plane Project is presented. The model requires the solution of transport equations for the Favre-averaged Reynolds stress tensor and dissipation rate. Gradient transport hypotheses are used for the Reynolds heat flux, mass flux, and turbulent diffusion terms. Some brief remarks are made about the direction of future research to generalize the model.

ICASE COLLOQUIA

April 1, 1989 - September 30, 1989

Name/Affiliation/Title	Date
Mr. Louis Howell, Massachusetts Institute of Technology "Ill-posedness of Absorbing Boundary Conditions for Migration"	April 4
Ms. Catherine Mavriplis, Massachusetts Institute of Technology "Adaptive Mesh Strategies for Spectral Element Techniques"	April 5
Dr. Clark Jeffries, Clemson University "Dense Memory with Neural Networks"	April 7
Mr. Andrew Meade, University of California, Berkeley "Experimental Study of Three-Dimensional Separated Flow Surrounding a Hemisphere-Cylinder at Incidence"	April 12
Professor Martin Lowson, University of Bristol, England "Experiments on Three-Dimensional Vortex Separations"	April 14
Dr. H. S. Mukunda, National Research Council Fellow, NASA LaRC "Stability and Transition in Premixed Laminar Flames"	May 3
Dr. Len Freeman, University of Liverpool and University of Manchester "Transputers, Occam and Parallel Algorithms for Polynomial Root-Finding"	May 4
Mr. Mark Jones, Duke University "Using the Method of Lanczos to Solve the Generalized Eigenvalue Problem in Structural Analysis"	May 24
Professor Michel F. Bosco, University of Massachusetts at Amherst "Storage Management Systems for Software Engineering Environments: from Concerto to Arcadia, through PCTE and IMPISH"	May 25
Professor Alfred C. Buckingham, Lawrence Livermore National Laboratory "Implications from Changes to Shock Structure in Shock Wave Turbulence Interactions"	June 13
Professor Peter Bernard, University of Maryland, College Park "A Re-Examination of Turbulent Vorticity Transport Theory"	June 27

Name/Affiliation/Title	Date
Professor Peter Fleming, University of Wales, United Kingdom "Parallel Processing Architectures and Applications for Real-Time Control"	June 29
Professor Peter Fleming, University of Wales, United Kingdom "Computer Aided Control System Design via Optimization"	June 30
Dr. Richard Barnwell, NASA Langley Research Center "A Skin Friction Law for Compressible Turbulent Flow"	July 6
Dr. Christine Bernardi, Universite Pierre et Marie Curie, France "Spectral Collocation Methods for Fourth-Order Problems"	July 13
Professor P. Sadayappan, Ohio State University "Parallel Execution of Irregular Doacross Loops"	July 31
Mr. Robert Leland, Oxford University "Parallel Iterative Algorithms for Sparse Linear Systems"	August 7
Dr. Marc Garbey, Argonne National Laboratory "Computation of Viscous or Non-Viscous Conservation Law Based on Asymptotic Analysis"	August 9
Professor Boleslaw Szymanski, Rensselaer Polytechnic Institute "Programming with Recurrent Equations"	August 14
Dr. Mark Holliday, Duke University "Some Issues Concerning Operating System Management of Distributed Shared Memory"	August 15
Dr. K. Dang, ONERA, France "Direct Simulations of Turbulent Channel Flows"	August 17
Dr. Roy Williams, California Institute of Technology "Distributed Computation of Transonic Flow with an Unstructured Mesh"	August 23
Dr. Jean Roberts, INRIA, France "Characterization of a Stratified Medium by a Method of Equivalent Impedances"	August 25

Name/Affiliation/Title	Date
Dr. Bjorn Engquist, University of California, Los Angeles "Projection Methods for Shock Capturing"	August 28
Dr. Jerome Jaffre, INRIA, France "Discontinuous Finite Elements for Nonlinear Hyperbolic Conservation Laws"	August 29
Professor Stanley Osher, University of California, Los Angeles "Numerical Front and Shock Capturing"	August 31
Ms. Smadar Karni, Cranfield Institute of Technology, England "One-Way Absorbing Boundaries for Time Dependent Hyperbolic Systems"	September 1
Dr. Akira Yoshizawa, University of Tokyo "Compressible Turbulence Modeling of Three-Equation Type"	September 8
Dr. Eli Turkel, Tel-Aviv University and ICASE "Improving the Accuracy of Central Difference Schemes"	September 13
Mr. Tom Kroupa, Intel Corporation "WARP - A System Architecture for High Performance Signal and Image Processing"	September 13
Professor Alexander Smits, Princeton University "Comparison of the Structure of Supersonic and Subsonic Turbulent Boundary Layers"	September 19
Professor David Gottlieb, Brown University "Tutorial on the Application of Boundary Conditions Stability Theory"	September 19 September 20 September 21
Dr. Eli Turkel, Tel-Aviv University "Asynchronous Schemes for Hyperbolic and Parabolic Time Dependent Equations"	September 21
Professor J. T. Stuart, Brown University "Lagrangian Picture of Fluid Motion and Its Implication for Flow Structures"	September 22
Professor Hillel Tal-Ezer, Tel-Aviv University "Modified Chebyshev Pseudospectral Method with $0(N^{-1})$ Time Step Restriction"	September 25

ICASE SUMMER ACTIVITIES

The summer program for 1989 included the following visitors:

NAME/AFFILIATION	DATE OF VISIT	AREA OF INTEREST
Saul S. Abarbanel Tel-Aviv University	6/26 - 9/15	Computational Fluid Dynamics
H. Thomas Banks Brown University	5/30-6/15	Control Theory
Christine Bernardi Universite Pierre et Marie Curie, France	7/3-7/15	Spectral Methods
H. Scott Berryman Yale University	7/5-Staff Appt.	Parallel Computing Systems
Richard J. Bodonyi Ohio State University	7/17-8/4	Boundary Layer Transition
Dennis W. Brewer University of Arkansas	6/12-6/16	Control Theory
John A. Burns VPI and State University	5/30-6/15	Control Theory
Stephen J. Cowley Imperial College, England	9/18-9/30	Computational Fluid Dynamics
John Crawford Brown University	6/15-6/22	Computational Fluid Dynamics
James M. Crowley Air Force Systems Command	6/12-6/16	Control Theory
Kay Crowley Yale University	7/3-7/14	Parallel Computing Environments
Michel Deville Universite Catholique de Louvain Belgium	7/30-9/1	Preconditioned Iterative Spectral Methods

NAME/AFFILIATION	DATE OF VISIT	AREA OF INTEREST
Wai-Sun Don Brown University	6/15-6/22	Computational Fluid Dynamics
Peter W. Duck University of Manchester, England	7/3-8/25	Numerical Solution of Unsteady Boundary Layer Equation
Richard Fabiano Brown University	6/12-6/16	Control Theory
Robert E. Fennell Clemson University	5/29-6/23	Control Theory
Daniele Funaro Universita di Pavia Italy	7/17-7/28	Spectral Methods for PDE's
J. Steven Gibson University of California, LA	6/13-6/19	Control Theory
David Gottlieb Brown University	7/10-9/1	Numerical Methods for PDE's
Chester E. Grosch Old Dominion University	5/1-8/1	Computational Fluid Dynamics
Philip Hall Exeter University, England	8/18-10/7	Computational Fluid Dynamics
Amiram Harten Tel-Aviv University, Israel	7/15-8/19	Numerical Methods for PDE's
Thorwald Herbert Ohio State University	7/24-8/4	Fluid Dynamics
Kazufumi Ito Brown University	6/7-6/13	Control Theory

NAME/AFFILIATION	DATE OF VISIT	AREA OF INTEREST
Thomas L. Jackson Old Dominion University	6/1-8/31	Numerical and Analytical Methods for Chemically Reacting Flows
Jerome Jaffe INRIA/France	8/14-9/1	Numerical Analysis for PDE's
Mark Jones Duke University	6/19-6/23 7/31-8/4 8/21-8/25	Algorithms for Parallel Array Computers
Ashwani K. Kapila Rensselear Polytechnic Institute	8/14-8/25	Mathematical Aspects of Combustion Processess
Smadar Karni Cranfield Institute of Technology, England	7/10-9/8	Numerical Solutions for the Euler Equations in Primitive Variables
Stephen Keeling Vanderbilt University	6/12-6/14	Control Theory
David E. Keyes Yale University	8/20-8/25	Parallel Methods Appropriate for Combustion Problems
Charles Koelbel Purdue University	7/10-7/14	Compilers for Parallel Machines
Yiing-Yuh Lin National Cheng Kung University, ROC	7/1-9/14	Optimal Control of Flexible Aircraft
Richard Littlefield Unviversity of Washington	7/10-7/14	Parallel Computing Environment
Robert W. MacCormack Stanford University	6/23-7/7	Numerical Methods for Hypersonic Flows
Yvon Maday Massachusetts Institute of Technology	7/10-7/15	Analysis of Spectral Methods
Ravi Mirchandaney Yale University	7/5-7/12 8/14-8/18	Analysis of Automated Parallel Problem Mapping Strategies

NAME/AFFILIATION	DATE OF VISIT	AREA OF INTEREST
Kirsten Morris The University of Waterloo, Canada	6/12-6/16 9/1-Staff Appt.	Control Theory
David M. Nicol College of William and Mary	6/1-9/1	Techniques for Mapping Algorithms onto Parallel Computing Systems
Stanley J. Osher University of California, LA	7/31-8/4	Numerical Techniques for Problems in Fluid Dynamics
Demetrius Papageorgiou City College of New York	7/15-8/22	Computational Fluid Dynamics
Merrell L. Patrick Duke University	5/1-9/1	Algorithms for Parallel Array Computers
Timothy N. Phillips University College of Wales	7/30-9/9	Numerical Methods for PDE's
Ugo Piomelli University of Maryland	7/24-8/4	Large Eddy Simulation
Daniel Reed University of Illinois, Urbana - Champaign	7/24-7/28	Performance Evaluation of Computer Systems
Jean Roberts INRIA/France	8/14-9/1	Numerical Analysis of PDE's
I. Gary Rosen University of Southern California	6/12-6/16	Control Theory
Joel H. Saltz Yale University	6/26-Staff Appt.	Analysis of Automated Parallel Problem Mapping Strategies
Paul E. Saylor University of Illinois, Urbana - Champaign	8/21-8/29	Iterative Parallel Methods for Linear Systems

NAME/AFFILIATION	DATE OF VISIT	AREA OF INTEREST
Chi-Wang Shu Brown University	6/18-7/22	Computational Fluid Dynamics
Frank T. Smith University College London, England	9/11-9/29	Theory and Computation of Boundary Layer Instabilities and Transition
Boleslaw Szymanski Rensselaer Polytechnic Institute	8/14-8/18	Programming Languages for Multiprocessor Systems
Shlomo Ta'asan The Weizmann Institute of Science	7/1-9/30	Multigrid Methods for PDE's
Eitan Tadmor Tel-Aviv University, Israel	7/6-Visiting Sc. Appt.	Numerical Methods for PDE's
Hillel Tal-Ezer Tel-Aviv University, Israel	8/14-9/15	Spectral Methods for PDE's
Saleh A. Tanveer Virginia Polytechnic Institute and State University	6/5-6/30	Vortex Methods for Fluid Dynamics Simulation
Roger Temam Universite de Paris-Sud, France	7/10-7/14	Numerical Methods for PDE's
Hien Tran Brown University	6/12-6/16	Control Theory
Eli Turkel Tel-Aviv University, Israel	6/19-7/28	Computational Fluid Dynamics
Bram van Leer University of Michigan, Ann Arbor	7/23-8/5	Computational Fluid Dynamics
Noel Walkington The University of Texas, Austin	6/12-6/16	Control Theory

OTHER ACTIVITIES

The Instability and Transition Workshop co-sponsored by ICASE and NASA Langley Research Center was held (May 15-June 9) at NASA Langley Research Center. One hundred and thirty people attended this workshop. The objectives of the workshop were to acquaint the academic community with the unique combination of theoretical, computational and experimental capabilities at LaRC and foster interactions with these capabilities; to expose the academic community to current technologically important issues of instability and transition in shear flows over the entire speed range; to review current state-of-the-art and propose future directions for instability and transition research; to accelerate progress in elucidating basic understanding of transition phenomena and in transferring this knowledge into improved design methodologies through improved transition modeling and to establish mechanisms for continued interaction. Invited speakers and their topics are listed below:

P. Bobbitt and D. Harvey, NASA Langley Research Center, Hampton, VA:
"Eight Foot Transonic Pressure Tunnel Laminar Flow Control Research"

P. Bobbitt, NASA Langley Research Center, Hampton, VA:
"Effects of Flow Quality on Transition"

D. Bushnell, NASA Langley Research Center, Hampton, VA:
"Applications of Transition Research"

M. Gaster, Cambridge University, England:
"Measurement Techniques"

P. Hall, Exeter University, England:
"Theoretical Tools"

B. Holmes, NASA Headquarters, Washington, DC:
"Flight Transition Research"

M. Morkovin, Professor Emeritus, Illinois Institute of Technology, Chicago, IL:
"Challenging Research Topics in Stability and Transition"
"Initiation and Evolution of Disturbances in Shear Flows"

R. Narasimha, National Aeronautical Laboratory, India:
"Modelling of Laminar Turbulent Transition"

R. Wagner, NASA Langley Research Center, Hampton, VA:
"Laminar Flow Control in Flight Research"

T. Zang, NASA Langley Research Center, Hampton, VA:
"Computational Tools"

In addition, the third week of the workshop was devoted to the following panel discussions:

"Theory Panel"

Sir James Lighthill, University College, England, Leader
M. E. Goldstein, NASA Lewis Research Center, Cleveland, OH
P. Hall, Exeter University, England
T. Herbert, Ohio State University, Columbus, OH
F. T. Smith, University College London, England

"High-Speed Transition Experiments Panel"

D. Bushnell, NASA Langley Research Center, Hampton, VA, Leader
I. E. Beckwith, NASA Langley Research Center, Hampton, VA
A. Demetriades, Montana State University, Bozeman, MT
J. M. Kendall, Jr., California Institute of Technology, Pasadena, CA
S. R. Pate, Arnold Air Force Base Station, Hampton, VA
E. Reshotko, Case Western Reserve University, Cleveland, OH
K. F. Stetson, Wright-Patterson Air Force Base, Dayton, OH

"Low Speed Experiments Panel"

P. J. Bobbit, NASA Langley Research Center, Hampton, VA, Leader
D. Arnal, ONERA/CERT - DERAT, France
T. C. Corke, Illinois Institute of Technology, Chicago, IL
M. Gaster, Cambridge University, England
L. Maestrello, NASA Langley Research Center, Hampton, VA
W. S. Saric, Arizona State University, Tempe, AZ

"Computation Panel"

S. A. Orszag, Princeton University, Princeton, NJ, Leader
H. Fasel, University of Stuttgart, Germany
P. R. Spalart, NASA Ames Research Center, Moffett Field, CA
C. L. Streett, NASA Langley Research Center, Hampton, VA
T. A. Zang, NASA Langley Research Center, Hampton, VA

"Receptivity Panel"

E. Reshotko, Case Western Reserve University, Cleveland, OH, Leader
D. Bushnell, NASA Langley Research Center, Hampton, VA
M. E. Goldstein, NASA Lewis Research Center, Cleveland, OH
L. S. Hultgren, NASA Lewis Research Center, Cleveland, OH
E. J. Kerschen, University of Arizona, Tucson, AZ
P. Leehey, Massachusetts Institute of Technology, Cambridge, MA

"Roughness Panel"

M. Morkovin, Illinois Institute of Technology, Chicago, IL, Leader
J. M. Kendall, California Institute of Technology, Pasadena, CA

A volume of the proceedings from this conference will be published by Springer-Verlag in the near future.

ICASE STAFF

I. ADMINISTRATIVE

Robert G. Voigt, Director Ph.D., Mathematics, University of Maryland, 1969 Numerical and Algorithms for Parallel Computers

Linda T. Johnson, Office and Financial Administrator

Judy Batten, Office Assistant, April-May, 1989

Etta M. Blair, Personnel/Bookkeeping Secretary

Barbara A. Cardasis, Administrative Secretary

Holly D. Joplin, Office Assistant, May-August, 1989

Rosa H. Milby, Technical Publications/Summer Housing Secretary

Cheryl A. Pruitt, Technical Publications Secretary

Emily N. Todd, Executive Secretary/Visitor Coordinator

II. SCIENCE COUNCIL for APPLIED MATHEMATICS and COMPUTER SCIENCE

Tony Chen, Professor, Department of Mathematics, University of California at Los Angeles.

John Hopcroft, Joseph C. Ford Professor of Computer Science, Cornell University.

Anita Jones, Chairman, Department of Computer Science, University of Virginia.

Robert MacCormack, Professor, Department of Aeronautics and Astronautics, Stanford University.

Joseph Oliger, Professor, Computer Science Department, Stanford University.

Robert O'Malley, Jr., Chairman, Department of Mathematical Sciences, Rensselaer Polytechnic Institute.

Stanley J. Osher, Professor, Mathematics Department, University of California.

Werner C. Rheinboldt, Andrew W. Mellon Professor, Department of Mathematics and Statistics, University of Pittsburgh.

John Rice, Chairman, Department of Computer Science, Purdue University.

Burton Smith, Tera Computer Company, Seattle, WA.

III. ASSOCIATE MEMBERS

Saul S. Abarbanel, Professor, Department of Applied Mathematics, Tel-Aviv University, Israel.

H. Thomas Banks, Professor, Center for Applied Mathematical Sciences, University of Southern California.

David Gottlieb, Professor, Division of Applied Mathematics, Brown University.

Peter D. Lax, Professor, Courant Institute of Mathematical Sciences, New York University.

Merrell L. Patrick, Professor, Department of Computer Science, Duke University.

IV. CHIEF SCIENTIST

M. Yousuff Hussaini - Ph.D., Mechanical Engineering, University of California, 1970. Computational Fluid Dynamics. (Beginning April 1978)

V. SENIOR STAFF SCIENTIST

Joel H. Saltz - Ph.D., Computer Science, Duke University, 1985. Parallel Computing with Emphasis on Systems and Algorithmic Issues. (July 1989 to September 1992)

Charles G. Speziale - Ph.D., Aerospace and Mechanical Sciences, Princeton University, 1978. Fluid Dynamics with Emphasis on Turbulence Modeling and the Transition Process. (September 1987 to September 1990)

John R. Van Rosendale - Ph.D., Computer Science, University of Illinois, 1980. Parallel Systems and Algorithms. (July 1, 1989 to July 1, 1991)

VI. SCIENTIFIC STAFF

Harry Scott Berryman - B.S., Computer Science, Yale University, 1988. Performance Analysis of Parallel Computing Systems. (July 1989 to July 1991)

Richard G. Carter - Ph.D., Numerical Analysis, Rice University, 1986. Numerical Methods for Optimization Problems. (September 1987 to September 1990)

Thomas W. Crockett - B.S., Mathematics, College of William and Mary, 1977. Parallel Systems Research. (February 1987 to February 1991)

Naomi Decker - Ph.D., Mathematics, University of Wisconsin-Madison, 1987. Multigrid Method Applied to Hyperbolic Equations. (September 1987 to September 1990)

Thomas M. Eidson - Ph.D., Mechanical Engineering, University of Michigan, 1982. Parallel Techniques for Computational Fluid Dynamics. (August 1989 to August 1991)

David Kamowitz - Ph.D., Computer Science, University of Wisconsin, Madison, 1986. Iterative Methods for Numerical Solutions of Partial Differential Equations. (September 1986 to September 1989)

Fumio Kojima - Ph.D., Control Theory, Kyoto University, Japan, 1985. Probabilistic and Stochastic Methods for Optimal Control Problems. (September 1986 to September 1990)

Dimitri Mavriplis - Ph.D., Mechanical and Aerospace Engineering, Princeton University, 1988. Grid Techniques for Computational Fluid Dynamics. (February 1987 to February 1990)

David J. Middleton - Ph.D., Computer Science, University of North Carolina, 1986. Design of Parallel Computing Systems. (November 1986 to May 3, 1989)

Kirsten Morris - Ph.D., Electrical Engineering, University of Waterloo, Canada, 1989. Control Theory. (September 1989 to September 1991)

Tobias B. Orloff - Ph.D., Mathematics, Princeton University, 1983. High Performance Graphics. (September 1988 to October 1989)

Yuh-Roung Ou - Ph.D., Aerospace Engineering, University of Southern California, 1988. Control Systems for Fluid Dynamics. (November 1988 to November 1990)

Douglas H. Peterson, Jr. - M.S., Computer Science, College of William and Mary, 1987. Computer Systems and Networking. (October 1985 to October 1989)

Peter W. Protzel - Ph.D., Electrical Engineering, Technical University of Braunschweig, Germany, 1987. Reliability of Computing Systems. (March 1987 to September 1990)

Sutanu Sarkar - Ph.D., Mechanical and Aerospace Engineering, Cornell University, 1988. Fluid Dynamics, Turbulence Modeling, Compressible Turbulence. (September 1988 to September 1990)

Jeffrey S. Scroggs - Ph.D., Computer Science, University of Illinois at Urbana, 1988. Domain Decomposition for Differential Equations. (July 1988 to July 1990)

Sharon O. Seddougui - Ph.D., Applied Mathematics, University of Exeter, England, 1988. Compressible Fluid Dynamics. (June 1988 to June 1990)

VII. VISITING SCIENTISTS

Christine Bernardi - Ph.D., Numerical Analysis, Universite Pierre et Marie Curie, Paris, 1986. Chargee de Recherche, Department of Analyse Numerique, Universite Pierre et Marie Curie. Spectral Methods. (July 1989)

Richard J. Bodonyi - Ph.D., Aeronautical and Astronautical Engineering, The Ohio State University, 1973. Professor, Department of Aeronautical and Astronautical Engineering, The Ohio State University. Boundary Layer Transition. (July to August 1989)

Charles-Henri Bruneau - Ph.D., Numerical Analysis, Universite Paris-Sud, Orsay, France, 1980. Assistant Professor, Department of Mathematics, Universite Paris-Sud, France. Navier-Stokes Equations. (March to May 1989)

Stephen J. Cowley - Ph.D., Mathematics, University of Cambridge, England, 1981. Lecturer, Department of Mathematics, Imperial College, England. Computational Fluid Dynamics (September 1989)

Michel Deville - Ph.D., Mechanical Engineering, University of Louvain, Belgium, 1974. Professor, Department of Mechanical Engineering, University of Louvain, Belgium. Spectral Methods. (July to September 1989)

Peter W. Duck - Ph.D., Fluid Mechanics, University of Southampton, United Kingdom, 1975. Lecturer in Mathematics, Department of Mathematics, University of Manchester, United Kingdom. Numerical Solution of Unsteady Boundary Layer Equations. (July to August 1989)

Richard H. Fabiano - Ph.D., Mathematics, Virginia Polytechnic Institute and State University, 1986. Visiting Assistant Professor, Department of Applied Mathematics, Brown University. Control Theory. (June 1989)

T. Leonard Freeman - Ph.D., Numerical Analysis, University of Liverpool, England, 1974. Lecturer in Mathematics, Department of Mathematics, University of Manchester, United Kingdom. Parallel Quasi-Newton Algorithms. (March to May 1989)

Daniele Funaro - Ph.D., Mathematics, University of Pavia, Italy, 1979. Researcher, Department of Mathematics, University of Pavia, Italy. Spectral Methods. (July 1989)

Philip Hall - Ph.D., Mathematics, Imperial College, England, 1973. Professor, Department of Applied Mathematics, University of Exeter, England. Computational Fluid Dynamics. (August to October 1989)

Jerome Jaffe - Ph.D., Numerical Analysis, University of Paris VI, France, 1974. Director de Recherche, Institut National de Recherche et Informatique et Automatique (INRIA). Numerical Methods for Partial Differential Equations. (August 1989)

Jacques Liandrat - Ph.D., Fluid Mechanics-Numerical Simulations, University of Toulouse, France, 1986. Research Scientist, I.M.S.T., Marseille, France. Turbulence Simulation. (October 1988 to September 1989)

Yiing-Yuh Lin - Ph.D., Mechanical Engineering, Virginia Polytechnic Institute and State University, 1988. Assistant Professor, National Cheng Kung University, Tainan, Taiwan. Control Theory. (July to September 1989)

Yvon Maday - Ph.D., Numerical Analysis, University of Paris, VI, 1981. Assistant Professor, Universite Pierre et Marie Curie, Paris, France. Analysis of Spectral Methods for Partial Differential Equations. (July 1989)

Piyush Mehrotra - Ph.D., Computer Science, University of Virginia, 1982. Assistant Professor, Department of Computer Science, Purdue University. Programming Languages for Multiprocessor Systems. (January to September 1990)

Ravi Mirchandaney - Ph.D., Computer Engineering, University of Massachusetts, 1987. Research Scientist, Department of Computer Science, Yale University. Parallel Computing. (July 1989)

Demetrius Papageorgiou - Ph.D., Mathematics, University of London, 1985. Research Associate, Department of Chemical Engineering, The City College of the City University of New York. Computational Fluid Dynamics. (July to August 1989)

Timothy N. Phillips - Ph.D., Numerical Analysis, Oxford University, England, 1983. Lecturer, Department of Mathematics, University of Wales, Aberystwyth, England. Numerical Methods for Partial Differential Equations. (July to September 1989)

Jean E. Roberts - Ph.D., Mathematics, University of Houston, 1976. Charge de Recherche, Institut National de Recherche en Informatique et en Automatique (INRIA). Computational Fluid Dynamics. (August to September 1989)

Frank T. Smith - Ph.D., Fluid Dynamics, Oxford University, England, 1972. Professor, Department of Mathematics, University College, United Kingdom. Boundary Layer Instabilities and Transition. (September 1989)

Boleslaw K. Szymanski - Ph.D., Computer Science, National Academy of Science, Warsaw, Poland, 1976. Design and Analysis of Parallel Algorithms. (August 1989)

Eitan Tadmor - Ph.D., Numerical Analysis, Tel-Aviv University, 1979. Senior Lecturer, Department of Applied Mathematics, Tel-Aviv University. Numerical Methods for Partial Differential Equations. (July 1989 to July 1990)

Hillel Tal-Ezer - Ph.D., Applied Mathematics, Tel-Aviv University, 1985. Instructor, Department of Mathematics, Tel-Aviv University, Israel. Spectral Methods for Partial Differential Equations. (August to September 1989)

Roger Temam - Ph.D., Numerical Analysis, University of Paris, 1967. Professor, Department of Mathematics, University of Paris XI. Numerical Methods in Fluid Dynamics. (July 1989)

Hein T. Tran - Ph.D., Mathematics, Rensselaer Polytechnic Institute, 1986. Assistant Professor, Division of Applied Mathematics, Brown University. Control Theory. (June 1989)

Noel J. Walkington - Ph.D., Mathematics, University of Texas, 1988. Lecturer, Department of Mathematics, University of Texas at Austin. Control Theory. (June 1989)

VIII. CONSULTANTS

Loyce M. Adams - Ph.D., Applied Mathematics, University of Virginia, 1983. Associate Professor, Department of Applied Mathematics, University of Washington. Numerical Methods for Parallel Computing Systems.

Alvin Bayliss - Ph.D., Mathematics, New York University, 1975. Associate Professor, Technological Institute, Northwestern University. Numerical Methods for Partial Differential Equations.

Marsha J. Berger - Ph.D., Numerical Analysis, Stanford University, 1982. Research Associate, Courant Institute of Mathematical Sciences. Numerical Methods for Partial Differential Equations.

Achi Brandt - Ph.D., Mathematics, Weizmann Institute of Science, 1965. Professor, Applied Mathematics Department, Weizmann Institute of Science, Israel. Multigrid Methods.

Dennis W. Brewer - Ph.D., Mathematics, University of Wisconsin, Madison, 1975. Associate Professor, Department of Mathematical Sciences, University of Arkansas. Methods for Parameter Identification and Estimation.

John A. Burns - Ph.D., Mathematics, University of Oklahoma, 1973. Professor, Virginia Polytechnic Institute and State University. Numerical Methods in Feedback Control and Parameter Estimation.

Stephen H. Davis - Ph.D., Mathematics, Rensselaer Polytechnic Institute, 1964. Professor of Engineering Sciences and Applied Mathematics, Northwestern University. Theory of Hydrodynamic Stability.

Peter R. Eiseman - Ph.D., Mathematics, University of Illinois, 1970. Senior Research Scientist and Adjunct Professor, Department of Applied Physics and of Nuclear Engineering, Columbia University. Computational Fluid Dynamics.

Robert E. Fennell - Ph.D., Mathematics, University of Iowa, 1969. Professor, Department of Mathematical Sciences, Clemson University. Control Theory for Multivariable Systems.

James F. Geer - Ph.D., Applied Mathematics, New York University, 1967. Professor, Systems Science and Mathematical Sciences, Watson School of Engineering, Applied Science and Technology, SUNY-Binghamton. Perturbation Methods and Asymptotic Expansions of Solutions to Partial Differential Equations.

J. Steven Gibson - Ph.D., Engineering Mechanics, University of Texas at Austin, 1975. Associate Professor, Department of Mechanical, Aerospace and Nuclear Engineering, University of California at Los Angeles. Control of Distributed Systems.

Chester E. Grosch - Ph.D., Physics - Fluid Dynamics, Stevens Institute of Technology, 1967. Professor, Department of Computer Science and Slover Professor, Department of Oceanography, Old Dominion University. Hydrodynamic Stability, Computational Fluid Dynamics, Unsteady Boundary Layers and Algorithms for Array Processors.

Max D. Gunzburger - Ph.D., Mathematics, New York University, 1969. Professor, Department of Mathematics, Virginia Polytechnic Institute and State University. Fluid Dynamics and Numerical Methods for Partial Differential Equations.

Amiram Harten - Ph.D., Mathematics, New York University, 1974. Associate Professor, Department of Mathematics, Tel-Aviv University, Israel. Numerical Solution for Partial Differential Equations.

Thorwald Herbert - Ph.D., Aerospace Engineering, University of Stuttgart, Germany 1978. Professor, Department of Mechanical Engineering, Ohio State University. Fluid Dynamics.

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